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Breeding Bermuda Grass for the Southeastern United States[1]

GLENN W. BURTON[2]

IN much of southeastern United States, Bermuda grass, *Cynodon dactylon* (L) Pers., is the most important pasture grass grown. Always a difficult weed to control in cultivated crop land, Bermuda grass has been despised and condemned by southern row-crop farmers for years. Livestock men in this area, however, have long recognized it as one of the best pasture grasses that can be grown. Many of them have considered it indispensable in their livestock program and have made an effort to increase its production. The recognition of the need for better varieties of Bermuda grass was responsible for the breeding project described here.

The major objective in the improvement of Bermuda grass by breeding was the development of more productive strains capable of supplying highly nutritious and palatable forage during a greater portion of the year. Resistance to disease (*Helminthosporium* sp.), drought, and frost injury were some of the specific objectives leading to this end. The ability to grow in association with southern legumes was considered to be an important characteristic. The desirability of creating tall-growing types suitable for hay production was emphasized by the need for an easily cured perennial hay crop in the Southeast. Sterile strains that would not seed or seed-producing strains that were non-stoloniferous were sought, since such strains would be more easily controlled and hence more generally accepted than common Bermuda grass by southeastern farmers. Since farmers had probably planted more Bermuda grass vegetatively than by seed, it was apparent that the improved strains could be economically propagated by either method.

MATERIALS AND METHODS

As far as the writer could discover, no attempts had been made to study the breeding behavior of Bermuda grass prior to this undertaking. In the absence of

[1]Cooperative investigations at Tifton, Georgia, of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station. Received for publication January 21, 1947.

[2]Geneticist, U. S. Dept. of Agriculture. The writer gratefully acknowledges the assistance of J. L. Stephens, B. L. Southwell, T. S. Boggess, and C. W. McBeth of the Georgia Coastal Plain Experiment Station, Tifton, Ga., and the farmers and men in research, extension, and soil conservation in the Southeast who have assisted in the evaluation of these Bermuda grasses.

such information, the following general observations were used in designing the Bermuda grass breeding project described here. Bermuda grass plants growing along a railroad right-of-way were found to be quite variable, suggesting that Bermuda grass might be a highly cross-pollinated species. Attempts to make controlled crosses between Bermuda grass plants indicated that such hybrids could be made. However, emasculating the small florets was so tedious and time-consuming that it seemed unwise at that time to plan a breeding program calling for much controlled hybridization. Consequently, a program was designed which would permit an analysis of the variation in the species and might very well give rise to certain superior individuals that could be propagated vegetatively.

In 1937 Tift Bermuda (4),[3] common Bermuda, and two tall-growing strains of Bermuda grass from South Africa were interplanted so that natural crossing could occur. Although the percentage of natural crossing that might occur was not known, it was believed that many natural hybrids would be produced, some of which might be the superior individuals sought. Enough open-pollinated seed was collected from these clones in 1937 to produce over 5,000 seedling plants, which were spaced 5 feet apart in 5-foot rows in the field in 1938. Attempts to produce self-pollinated seed in bags on the parent clones met with little success and selfed progenies were not available for study until 1941. During the summer several ratings on vigor and spread were obtained for each plant. Stem length and leaf length were measured and the heading date was recorded. In September each plant was rated from 1 to 5 on the basis of its resistance to *Helminthosporium* sp. leaf spot. A head-abundance rating was made and the percentage of florets to set seed was determined in October. Ratings on head abundance and spring growth, and a determination of the percentage of florets to set seed were obtained in 1939.

On September 13, 1938, clones from 128 of the 5,000 seedlings were planted in triplicate in 4-inch clay pots in a mixture of 50 grams of well-rotted manure and 1 pound of soil. Each replicate was placed in a large flat pan in the greenhouse and was watered by filling the pan with water to a certain level each morning. Selection of the clones was based on the records mentioned above and the appearance of the plants. A representative series of the major morphological types was included. The grass in each pot was then clipped at 3-week intervals throughout the winter and the dry weights of the clippings in grams were recorded. The totals of these weights make the 1939 greenhouse yields referred to later in this paper.

Nineteen additional clones that looked unusually good in the spring of 1939 were selected from the original 5,000. Sod of these, together with sod from the potted clones in the greenhouse, was planted in the centers of 4×24 foot plots in triplicate on April 3, 1939. The soil not occupied by stolons was kept free of weeds in 1939. Four-foot cultivated alleys were maintained between the plots throughout the test to prevent the stolons of one plot from growing into and contaminating another. Several measurements of the length of the stolons and the area occupied by each clone during the first year of this test supplied valuable information on the comparative rate of spread of each strain. From 1939 to 1946 these plots were uniformly fertilized each year with a complete commercial fertilizer, 4–12–4 or something similar, at the rate of 500 pounds per acre. They were never turned or scarified during that time.

Crimson clover was seeded at a rate of 30 pounds per acre over all plots in November 1941 and November 1942 to permit a study of the interaction of crimson clover and these strains when grown together. In late February of the years 1944, 1945, and 1946, Kobe lespedeza was seeded at a rate of 40 pounds per acre on the same half of each Bermuda grass plot. The behavior of the grass and lespedeza in this association has been studied each season. Over 50 observations have been recorded for each plot from 1939 through 1946. Many of these records, such as sod density, head abundance, frost resistance, disease resistance, vigor, color, percentage weeds, and percentage cover were visual estimates. Where ratings were made, the most desirable characteristic was given a rating of 1. All hay yields were obtained by cutting the plots with a sickle bar mower and weighing the air-dry hay after it had completely cured in the swath. All heads (digitate spikes) from a square foot of each plot were harvested and threshed to give the seed yields of each strain. The percentage of seed set was determined by methods described in detail elsewhere (2). The percentage of crimson clover in the hay

[3]Figures in parenthesis refer to "Literature Cited", p. 568.

reported in Table 3 was ascertained by making separations of fresh samples taken from each plot. The methods used in studying the lespedeza-grass association and the nematode resistance of the grasses have been described (6). Correlation coefficients were calculated to show the relationship between some of the characteristics of the strains studied in this test. They are presented in Table 1.

On March 24, 1941, five of the best Bermuda selections from the test just described were planted in duplicate tenth-acre plots in 3×3 and 6×6 foot spacings. Five different annual fertilizer treatments were located at random upon each plot. The variation in the response of three of these selections, when grown with and without fertilization for a 5-year period, is shown in Table 4. The fertilized plots referred to in Table 4 were treated alike, receiving 250 pounds of 0–16–8 and from 400 to 800 pounds of nitrate of soda per acre annually. The nitrate of soda top dressings were applied at the rate of 200 pounds per acre following the removal of each cutting of hay. The yield and chemical composition of the herbage of the five selections in this test are presented in Table 5.

Nine selections of Bermuda grass were planted on July 31, 1941, in duplicate 30×60 foot plots in a pasture that was later grazed by Jersey cattle. The comparative palatability of these strains was measured by noting the amount of forage removed from each plot and by recording the distribution of 20 or more animals on the plots at 5-minute intervals. In the latter method, notes were taken only when there was an abundance of forage on all plots. Total cow hours were determined by multiplying the number of cows on any plot by 5 and dividing by 60, the number of minutes in an hour. Since the animals had free choice of the forage in each plot, this palatability test pasture was named the Bermuda grass "cafeteria" (5). The striking differences in the palatability of the strains included in the cafeteria are shown in Fig. 3 and Table 6.

On June 29, 1943, nine selections of Bermuda grass were planted in 6×18 foot plots in quadruplicate. All were well established by fall. Beginning in the spring of 1944, these plots were clipped with a power mower at frequent intervals to simulate close grazing. All clippings were collected, dried, and weighed. A summary of the 1945 production of these strains appears in Table 7.

Limited cytological investigations were conducted during the course of these investigations. The techniques described elsewhere (3) were used in studying the morphology and number of chromosomes in the root tips of several different Bermuda grass plants including the ones used as parents in these studies.

Small quantities of stolons of several of the best Bermuda selections were sent to representatives of a number of the experiment stations in the Southeast in 1941. Early reports from these stations suggested that some of these selections were widely adapted and offered considerable promise. Beginning in 1943 many letters were received from farmers requesting stolons of selection No. 35, described and named Coastal Bermuda (4). In response to these requests stolons of Coastal Bermuda were shipped to over 2,000 farmers in southeastern United States during the years 1943 to 1946. A questionnaire sent to some of these farmers in the fall of 1946 furnished the information considered in the section dealing with the adaptability of Coastal Bermuda.

RESULTS

In most of the root-tip material of Bermuda grass examined at Tifton, chromosome fragments of varying size and number were observed in association with the chromosomes. These fragments, some of which approached the size of chromosomes, made it difficult to study accurately the complement in any plant. A study of mitotic figures from a number of selections indicated that the somatic chromosome number of *Cynodon dactylon* is probably 36 and several fragments. Avdulov (1) found that Bermuda grass contained 36 somatic chromosomes. Hunter (7), on the other hand, reported 30 as the 2n number in the material that he examined.

To date no effort has been made to study the genetics of Bermuda grass. Without genetic markers, the inheritance of which is known, the

percentage of natural crossing cannot be accurately determined. Some light was thrown on this question, however, when it was discovered that a small selfed progeny of Tift Bermuda was remarkably uniform in its semi-decumbent growth habit. In the 1938 planting of open-pollinated seedlings of Tift Bermuda, less than 20% of the plants showed this same semi-decumbent habit of growth. This observation, together with the extreme range of variability to be found in spaced seedlings of the species would seem to indicate that *Cynodon dactylon* is a highly cross-pollinated species.

All controlled crosses that have been made have exhibited characteristics of both parents in the F_1. There has been no evidence in the breeding behavior of Bermuda grass to suggest that it reproduces itself by apomixis.

Very striking variations were observed in the 5,000 spaced seedlings of Bermuda grass planted in the spring of 1938. No two plants appeared to be exactly alike. Although they differed greatly in rate of spread, all of them had both stolons and rhizomes.

The 147 selections included in the triplicated 4 x 24 foot plot test varied significantly in sod density, head abundance, frost resistance, disease resistance, root-knot resistance, vigor, color, percentage of weeds, percentage of cover, and rate of spread. When cut for hay, some of the best selections yielded over four times as much as some of the poorest ones. Many of the best selections, like the one named Coastal, differed so much from small inbred progenies of their female parents that it was quite evident that they were F_1 hybrids. Calculated seed yields ranged from less than 1 pound to more than 250 pounds of seed per acre. Wide differences in percentage seed set were also observed.

PLANT CHARACTER RELATIONSHIPS

It is not known at present how many years of testing should go into the evaluation of any particular strain or strains of the perennial grasses. In an effort to answer this question, correlation coefficients were calculated for a number of the measurements made on the 1947 selections in this test. These appear in Table 1.

The hay yield obtained on October 3, 1940, represented the total production of each strain for 1940, the first year after the establishment of the plots. It is interesting that this yield should have correlated significantly with the yield rating made June 13, 1938, less than 3 months after the seedlings were set out. A higher correlation coefficient of + .43 was obtained between this rating and the total hay yield from 1940 to May 7, 1943. These coefficients, though not large, indicate that yield ratings made the first year on spaced seedlings should be of value in eliminating many of the low-yielding individuals.

Table 1 shows that there was no relationship between the total greenhouse yields and the hay yields obtained later in the field. The fact that the greenhouse yields were taken during the winter under very different growing conditions than those experienced in the field no doubt affected the results obtained. These insignificant correlations indicate that such greenhouse yields obtained during the

TABLE 1.—*The relationships between a number of Bermuda grass characters as measured by correlation coefficients.*

Characters correlated		n	Correlation coefficient
Yield rating June 13, 1938	Hay yield Oct. 3, 1940	132	+.34**
Yield rating June 13, 1938	Total hay yield Oct. 3, 1940 to May 7, 1943	134	+.43**
Total greenhouse clipping yields	Hay yield Oct. 3, 1940	126	+.07
Total greenhouse clipping yields	Total hay yield Oct. 3, 1940 to May 7, 1943	126	+.11
Hay yield Oct. 3, 1940	Total hay yield Oct. 3, 1940 to May 7, 1943	137	+.80**
Seed yield July 9, 1941	Hay yield Oct. 3, 1940	139	−.08
Seed yield July 9, 1941	Total 1941 hay yield	147	+.10
Seed yield July 9, 1941	Head abundance July 10, 1939	65	+.23
Seed yield July 9, 1941	Per cent caryopses July 9, 1941	143	+.59**
Per cent caryopses July 1939	Per cent caryopses July 9, 1941	76	+.50**
Clover and grass hay yield May 7, 1942	Hay yield June 25, 1942	147	+.29**
Clover and grass hay yield May 7, 1942	Hay yield Aug. 10, 1942	147	+.27**
Hay yield June 25, 1942	Hay yield Aug. 10, 1942	147	+.78**
Per cent of Bermuda grass Oct. 19, 1943	Sod density Aug. 26, 1939	147	+.20*
Per cent of Bermuda grass Oct. 19, 1943	Length of stems Nov. 15, 1939	147	+.68**
Per cent of Bermuda grass Oct. 19, 1943	Hay yield Oct. 3, 1940	147	+.56**
Per cent of Bermuda grass Oct. 19, 1943	Per cent ground cover May 9, 1940	147	−.44**
Per cent of Bermuda grass Sept. 20, 1946	Sod density Aug. 26, 1939	147	−.06
Per cent of Bermuda grass Sept. 20, 1946	Length of stems Nov. 15, 1939	147	+.44**
Per cent of Bermuda grass Sept. 20, 1946	Hay yield Oct. 3, 1940	147	+.55**
Per cent of Bermuda grass Sept. 20, 1946	Per cent ground cover May 9, 1940	147	−.19**

*Exceeds the 5% point of significance.
**Exceeds the 1% point of significance.

winter will be of no value in determining the true yield performance of Bermuda grass selections.

The high positive correlation of .80 obtained between the 1940 hay yield and the total hay production up to May 7, 1943, indicates that the hay yields obtained the first year after establishment should give an excellent index of later yield performance when cut for hay. That such yields may not give a true picture of the yield performance when clipped frequently will be shown later.

Seed yield July 9, 1941 in these 147 selections was not correlated with hay yield October 3, 1940, total 1941 hay yield, or head abundance ratings made July 10, 1939. The correlation coefficient between seed yield July 9, 1941, and the percentage of caryopses July 9, 1941, was a highly significant + .59. Since the percentage of caryopses in July 1939 and on July 1941 were significantly correlated, it is evident that this characteristic may be measured early in the evaluation of a strain. Considerable variation in percentage seed set was observed between strains. Coastal Bermuda, for instance, was highly sterile, while a few clones produced seed containing as much as 75% of caryopses by weight.

The correlation between the hay yields of clover and grass mixed and of grass alone later in the season were very small but significant. On the other hand, the hay yields of the grass alone on June 25, 1942, and August 10, 1942, were closely related, giving a correlation coefficient of + .78. An explanation of these relationships may be found in the 1943 data presented in Table 2. These results are very similar to those obtained in 1942. In this table, it may be seen that the actual yields of clover were about the same with both the common and hay-type Bermudas. Therefore, since grass made up a very small proportion of the May 7 cutting, a close relationship between the hay yields of the clover and grass mixed and the later hay yields of the grass alone would not be expected. More mixed hay was taken from the hay-type plots than from the common-type plots because there was more Bermuda grass in the mixed hay from the hay-type plots. This difference is shown in Fig. 1.

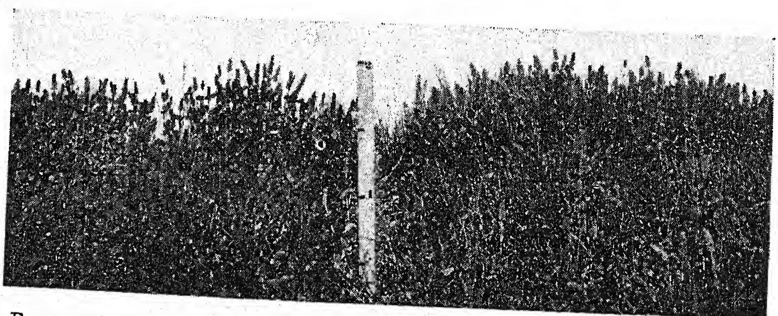

FIG. 1.—Crimson clover growing on a common strain Bermuda plot on the left and a hay strain Bermuda plot on the right on May 1, 1942.

TABLE 2.—*A comparison of the behavior of ten common and ten hay-type Bermuda selections when grown clonally in association with crimson clover.**

Selection No.	Hay yield, clover and grass mixed, lbs., May 7, 1943	Percentage crimson clover in the hay, dry basis, May 7, 1943	Pounds of clover in hay, May 7, 1943	Estimated percentage of weeds, June 18, 1943	Hay yield, lbs., June 21, 1943	Hay yield, lbs., Aug. 3, 1943	Estimated percentage of weeds, Oct. 18, 1943	Hay yield, lbs., Oct. 18, 1943
				Common Types				
21	2.5	97.2	2.43	86.7	0.6	3.2	66.7	1.9
47	3.4	97.4	3.31	80.0	0.7	3.0	91.7	2.5
50	2.8	99.0	2.77	86.7	1.1	2.3	66.7	3.1
51	2.7	97.4	2.63	80.0	0.9	3.2	95.0	2.2
61	3.1	91.5	2.84	30.0	2.2	4.5	28.3	1.9
67	3.7	86.7	2.00	15.0	2.4	3.5	13.3	2.5
68	3.3	90.0	2.97	16.7	2.4	3.0	41.7	2.1
71	2.7	95.5	2.58	80.0	0.9	3.6	91.7	1.9
81	3.6	94.4	3.40	36.7	1.7	2.9	15.0	2.1
117	4.1	98.7	4.05	68.3	1.4	2.9	45.0	2.4
Mean......	3.19	94.78	3.019	58.01	1.43	3.24	55.51	2.76
				Hay Types				
28	3.6	84.9	3.06	6.7	3.3	5.0	3.0	4.6
46	3.5	75.9	2.66	11.7	4.2	5.3	8.3	4.1
53	3.5	75.1	2.63	7.3	3.9	4.4	7.3	3.8
74	3.2	77.8	2.49	16.7	3.6	4.3	11.7	3.5
76	4.0	84.4	3.38	11.7	3.8	6.0	10.0	4.5
89	3.4	86.7	2.95	10.0	3.7	5.4	15.0	3.0
91	3.5	87.6	3.07	13.3	4.3	4.2	16.7	3.5
103	3.3	80.8	2.67	4.0	3.6	3.3	4.0	2.7
104	4.0	80.6	3.22	4.0	5.3	6.2	5.0	4.0
119	4.0	77.0	3.08	11.7	5.9	5.0	7.3	4.7
Mean......	3.60	81.08**	2.921	9.71**	4.16**	4.91**	8.83**	3.84**

*Crimson clover dies after the May cutting and remaining hay yields are of grass alone.
**"F" exceeds 1% level of significance. Only significant means are starred.

PLANT TYPE AND CRIMSON CLOVER

The data in Table 2 and Fig. 2 show that weeds were much more prevalent in the common-type plots on June 24, 1942, than in the hay-type plots. The common-type Bermudas undoubtedly suffered more from competition with crimson clover than the hay-type Bermudas because they could not grow tall enough to get into the sunlight. As soon as the first cutting of hay was removed, the hay-type Bermudas made a very rapid recovery largely eliminating weeds. The common types, on the other hand, grew slowly and permitted fast-growing annual weeds to become established. All hay yields presented in Table 2 include the weight of the weeds. If corrections be made for the weeds, the yield differences become even greater in favor of the hay-type Bermudas. The weed estimates made October 18, 1943, were very similar to those made June 16, 1943. It is evident that the hay-type Bermudas can compete with weeds more successfully than the common Bermudas under a hay production type of management.

FIG. 2.—The aftermath on the two plots pictured in Fig. 1 following the removal of the crimson clover hay. Note the many annual weeds in the common Bermuda plot on the left. Photographed June 24, 1942.

LONGEVITY

Longevity, or the ability to persist over a number of years, is one of the most important characteristics of any pasture or hay plant. It has been generally recognized that scarification or turning of common Bermuda sod every 3 years is necessary in order to maintain a good sod on soils of the type used in these tests. It was not surprising, therefore, to observe most of the common-type Bermudas "going out" at the end of 4 years. By September 20, 1946, the Bermuda grass had almost completely disappeared from some of the plots and weeds had taken its place. In an effort to discover what early measurements might be used to indicate the longevity of a selection, a number of correlation coefficients were calculated. Some of the more significant

of these are presented in Table 1. It is evident from these correlations coefficients that length of stems November 15, 1939 and hay yield October 3, 1940 are more closely related to the percentage of Bermuda grass in the fall of 1943 and 1946 than any of the other early measurements. Thus it may be concluded that, when mowed for hay, the long-stemmed, high-yielding hay types will generally maintain a good stand longer than the common types. Table 3, which gives a more detailed record of the performance of some of these strains, shows that common strains, such as selection 14, can be found which will maintain much better stands than most common strains under such management.

TABLE 3.—*Establishment and stand maintenance in Bermuda grass selections as influenced by strain characteristics and management practices.*

Strain No.	Sod density rating Aug. 26, 1939*	Length of stems in inches Nov. 15, 1939	Percentage ground cover May 9, 1940	Yield of cured hay, lbs. per plot Oct. 3, 1940	Percentage stand when			
					Cut for hay			Clipped frequently with lawn mower for 3 years
					May 1941	After 4 years	After 7 years	
				Common Types				
21	6	12	92	3.2	93	33	5	62
47	7	12	90	2.4	83	8	8	—
50	3	12	84	2.6	93	33	22	—
14	6	16	96	5.1	97	87	65	96
				Hay Types				
Tift	9	25	45	4.9	83	93	83	75
Coastal	5	30	87	10.4	92	97	90	82
3	4	23	91	9.9	97	96	95	95
36	6	32	47	9.1	98	90	73	66
85	4	36	36	9.3	85	88	53	57
99	4	35	35	10.1	95	92	70	10
104	6	23	23	8.1	98	95	87	74
Least significant 5% difference†		6	30	3.6		37	36	17

*The lower the rating value, the greater the sod density.
†The absence of a 5% mean difference value indicates that the differences are not significant.

LESPEDEZA AND NEMATODE RESISTANCE

Kobe lespedeza was planted on half of each plot of these 147 strains of Bermuda grass in February of the years 1944, 1945, and 1946 in in order to determine if it would grow well in association with the tall hay-type Bermudas. It was soon found that the growth and persistence of Kobe lespedeza was not influenced by the growth habit or type of the Bermuda selection. It was found, however, to be associated with the root-knot-nematode resistance of the Bermuda grass

clone (6). Striking differences in the root-knot resistance of different Bermuda selections were observed. Repeated attempts to infect Coastal Bermuda artificially with root knot failed, indicating that it was immune to the races of root knot nematode used.

HAY PRODUCTION

The yield data in Table 4 show that the yield performance of Bermuda grass strains is influenced by the age of the sod and the fertilization treatment. During the first two years of the test, Coastal Bermuda outyielded selections 3 and 99 regardless of the fertilization treatment. It continued to outyield selection 3 throughout the test when fertilized but yielded slightly less than this selection in 1945 when not fertilized. In the last two years of the test selection 99 yielded more than twice as much as Coastal Bermuda without fertilizer, but yielded very little more when fertilized. These results indicate that Coastal Bermuda would probably continue to outyield selections 3 and 99 if the fertility were maintained at a high enough level. Where the soil fertility is low and in the absence of a continued fertilization program, selection 99 would appear to be the most productive of the three. These findings emphasize the importance of testing strains of perennial plants at different fertility levels over a period of several years.

TABLE 4.—*The influence of age of sod and fertilization upon the annual hay production of three strains of Bermuda grass.*

Year	Total pounds of hay produced per acre by years					
	Selection No. 3		Coastal		Selection No. 99	
	Fertilized	Not fertilized	Fertilized	Not fertilized	Fertilized	Not fertilized
1941	1,391	815	1,767	1,454	1,550	901
1942	9,500	2,595	10,210	2,950	8,047	2,262
1943	4,235	1,050	5,900	1,880	7,300	2,765
1944	7,580	680	9,910	1,370	11,020	4,100
1945	7,810	1,520	9,165	1,415	9,430	3,530
Total...	30,516	6,660	36.952	9,069	37,347	13,558

CHEMICAL COMPOSITION

On August 18, 1942, 40 days after the previous cutting, the five Bermuda selections in the hay production test just described were cut for hay. Hay samples from the fertilized and unfertilized plots of each selection were analyzed for the chemical constituents shown in Table 5. Statistical analyses of these data revealed that fertilization (500 pounds of 4–8–4 applied May 20, 1942, and 240 pounds of nitrate of soda applied July 11, 1942) increased the yield of hay four fold, decreased the dry matter in the grass from 43.2% to 37.5%, increased the crude protein from 6.46% to 7.72%, and increased the lignin from

9.96% to 10.41%. Fertilization had no significant effect upon the percentage of the other chemical constituents in the hay. These results were probably influenced by the fact that the Tifton sandy loam on which this test was conducted had grown fertilized crops for many years previous to the initiation of this experiment.

The figures presented in Table 5 are the average of data from two fertilized and two unfertilized plots of each selection. The averaging of these data seemed justified, since significant strain treatment interactions were obtained only for ether extract and calcium, and these interactions were of small magnitude. The statistical constants included in Table 5 show that the five strains differed significantly in all measurements except ash and phosphorous content. The differences were not great, however, and the analyses for all of the strains compared favorably with analyses of other grass hays such as timothy (8). Hay made from these Bermudas was ready to put in the barn after 24 to 48 hours of curing in the swath, and when cut and cured properly it was readily eaten by mules and cattle.

PALATABILITY

When Jersey cattle, mature cows or heifers, were allowed to graze at will in the Bermuda grass strain cafeteria, they showed definite preferences for some strains. As Table 6 indicates, these animals remained on the most palatable plots for the longest period of time and grazed such plots more closely than adjacent plots of less palatable selections. The differences in grazing intensity were so great and were so sharply defined between strains that plot boundaries could be easily found, using intensity of grazing as the only guide. This difference in intensity of grazing is well demonstrated in Fig. 3. In this test Coastal Bermuda was one of the most palatable clones, while common Bermuda and selections 3 and 60 were the least palatable. In an effort to explain these differences in palatability, samples taken from the common and Coastal Bermuda plots were analyzed for all of the chemical constituents listed in Table 5. The differences between the analyses of the common and Coastal Bermuda samples were slight and in no case approached statistical significance. It is of interest to note that three different men were unable to detect any differences in the taste of these strains. It has been suggested that fine-stemmed grasses are more palatable than coarse-stemmed ones. In this test the unpalatable selection 3 was the finest stemmed clone, while the highly palatable Coastal was the coarsest. It was impossible to associate these palatability differences with morphological differences in the strains in question.

REACTION TO CLOSE CLIPPING

An experiment designed to test the productivity and persistence of nine strains of Bermuda grass when clipped frequently to simulate close grazing was begun June 29, 1943. The four plots of each selection were planted with uniform quantities of stolons of each clone, were kept free of weeds, and were not clipped until October 24, 1943. At that time an average of 0.37 pound of dry matter was taken from

TABLE 5.—*The yield and chemical composition of five strains of Bermuda grass cut for hay August 18, 1942.*

Strain of Bermuda grass	Yield of dry matter, lbs. per acre	Percentage of dry matter in green grass	Chemical composition of oven-dry samples*								
			Ash, %	Ca, %	P, %	Crude protein, %	Ether extract, %	Crude fiber, %	Cellulose, %	Lignin, %	Undigested residue, %
Tift	1,225	40.7	4.73	0.348	0.205	7.73	2.44	30.57	33.85	9.94	60.66
No. 3	1,549	41.4	4.65	0.306	0.209	6.61	2.02	27.68	29.44	9.70	57.30
No. 13	1,788	42.1	4.92	0.379	0.198	6.87	1.97	28.98	30.51	9.65	59.15
Coastal	1,868	39.9	4.64	0.304	0.205	6.70	2.32	29.91	32.44	10.99	58.38
No. 99	1,552	37.5	4.37	0.306	0.188	7.63	2.51	31.33	33.56	10.64	60.93
Least significant 5% difference†	270	1.7		0.012		0.56	0.37	1.48	1.06	0.62	2.90

*Official A. O. A. C. Methods. The chemical analyses were made by T. S. Boggess, Chemist at the Georgia Coastal Plain Experiment Station.
†The absence of a 5% mean difference value indicates that the differences are not significant.

TABLE 6.—*The comparative palatability of nine strains of Bermuda grass grown in duplicate plots in a Bermuda grass cafeteria at Tifton, Ga.*

Strains	Average percentage of the total cow hours spent on each strain in 1942 and 1943	August 14, 1944, rating on the amount of grass left after a period of continuous grazing*		
		Rep. 1	Rep. 2	Av.
Common	9.1	5.0	5.0	5.00
Coastal	14.9	1.0	1.5	1.25
3	13.8	4.5	5.0	4.75
13	14.1	1.0	1.0	1.00
36	7.8	3.5	4.0	3.75
60	6.8	5.0	5.0	5.00
85	8.1	3.0	3.0	3.00
99	14.3	2.0	2.0	2.00
107	11.0	3.5	4.0	3.75

*Plots rated 1 were grazed closely; those rated 5 were grazed very little.

each plot of common Bermuda as compared with 4.92 pounds from the average Coastal Bermuda plot. These striking differences in production are shown in Fig. 4.

Table 7 presents the 1945 seasonal production of these nine Bermuda grass strains when clipped frequently to simulate close grazing. These results are similar to those obtained in 1944 and 1946, and indicate that selection 3 will outyield all other selections in the test

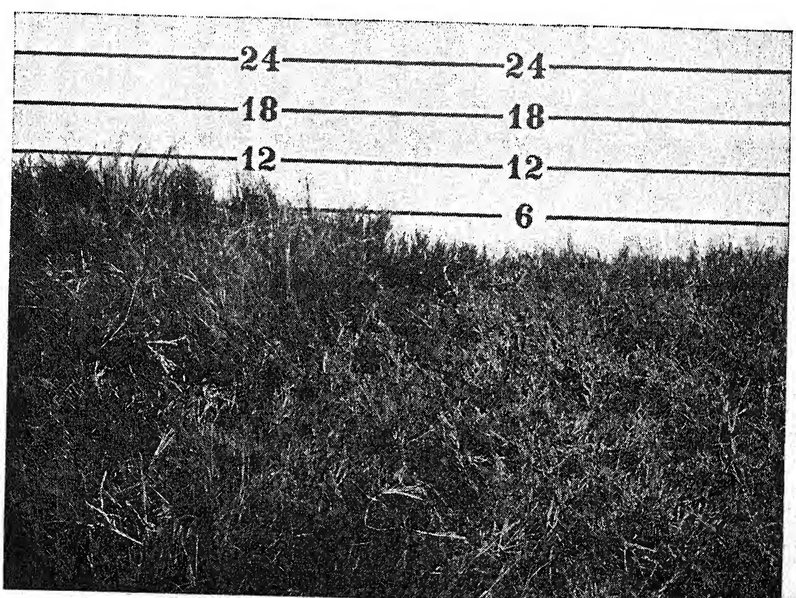

FIG. 3.—Bermuda grass selection No. 3 on the left and Coastal Bermuda on the right occurring in the Bermuda cafeteria. The difference in grazing intensity demonstrates the greater palatability of Coastal Bermuda.

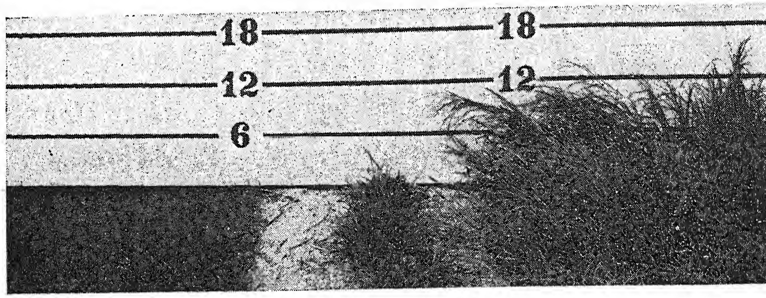

FIG. 4.—Plots of common Bermuda grass on the left and Coastal Bermuda on the right photographed September 13, 1943. Both plots were planted in the same manner on June 29, 1943.

when clipped frequently. This selection starts growth very early in the spring and has consistently produced twice as much forage as the other selections during the spring season. These data suggest that selection 3 would be the most productive of these strains for closely grazed pastures. The data in Table 7 show the existence of striking differences in the seasonal production of Bermuda grass selections. Obviously, the choice of a strain will be influenced considerably by the seasonal feed requirements. In the Coastal Plain of the southeastern United States, for instance, the burned over native grasses supply an abundance of good early spring grazing but supply very poor summer and fall pasturage. Consequently, the greatest need in this region is for those selections that excel in summer and fall production.

TABLE 7.—*The 1945 dry matter production of nine strains of Bermuda grass when clipped at frequent intervals with a power lawn mower at Tifton, Ga.*

Strain	Pounds per acre of dry matter produced during the following periods			
	First growth to May 30	May 30 to Aug. 15	Aug. 15 to Oct. 17	Total
Common	289	245	283	816
Coastal	556	763	815	2,135
Selection No. 3	1,257	835	711	2,803
Selection No. 99	287	637	474	1,398
Selection No. 104	533	979	664	2,177
Tift	337	558	371	1,266
Selection No. 36	498	730	487	1,715
Selection No. 85	624	1,142	772	2,538
Selection No. 14	541	598	381	1,521
Least significant 5% difference	125	164	169	389

REGIONAL ADAPTATION

From 1940 to 1942, sprigs of several of the best Bermuda grass selections were sent to a number of experiment stations. Reports from

these stations revealed that selection 99 lacked cold resistance and that selection 35 was perhaps the most widely adapted of any of them. Consequently, selection 35, which had been outstanding in other tests, was described (3) and named "Coastal Bermuda" for the experiment station where it was developed. As a result of several references to Coastal Bermuda in farm papers, requests for planting material came in from all of the states in the Southeast. From 1943 to 1946, a small quantity of stolons of Coastal Bermuda grass was shipped to some 2,000 farmers in these states. Records of all shipments were kept.

In order to obtain a farmer reaction and some information on the range of adaptability of Coastal Bermuda grass, a questionnaire was mailed to some 200 farmers in the southeastern states in the fall of 1946. Of the farmers who answered the questionaire, one-fourth said that the stolons were either dead from desiccation upon their arrival or died for lack of water when they were set out in the field. The shipping losses resulted from the use of packing methods not designed for the shipping delays experienced during the war. Perhaps the question best indicating the farmers' opinion of the grass was, "Do you intend to plant more Coastal Bermuda grass?" Eighty-eight per cent of those who obtained a good stand said, "Yes". The letters received indicated that Coastal Bermuda will survive the winters as far North as the southern boundary of Tennessee, and suggest that it may be winterhardy as far north as the northern boundary of Tennessee except for the mountainous sections. South of this line it appears that it will grow wherever common Bermuda will grow.

GRAZING RESULTS

The best measure of the value of any new grass is the pounds of livestock products that it will produce per acre. In the spring of 1944, a 6-acre pasture located on a Tifton sandy loam was planted to Coastal Bermuda. Five hundred pounds of 4–8–4 fertilizer were applied per acre at planting time. Sprigs of the grass were then planted 5 feet apart in 5-foot rows and were cultivated twice during the summer. Although this pasture was not completely covered with Bermuda grass in the spring of 1944, six animals grazed it from April 12 to November 8. Three more animals were added on June 30. During the 1944 grazing season this pasture produced 252 pounds of beef gain per acre. In 1945, it carried eight animals for 224 days and produced 338 pounds of beef gain per acre. Nitrate of soda was applied to this pasture in 1944 and 1945 at the rate of 200 pounds per acre. The pasture fertilization plan calls for the application of phosphorous and potash at the rate of 600 pounds of 0–12–6 per acre every third year. Common Bermuda grass growing on similar soil and receiving the same fertilization carried not more than one animal to the acre and produced an average of 149 pounds of beef per acre for a 6-year period. Coastal Bermuda gave unusually good gains in the late summer and fall when other grass pastures produced little beef.

ESTABLISHMENT

Many will ask, "Is it practicable to plant a pasture grass vegetatively?" This question can best be answered by describing one planting made in 1946. Farm laborers with standard tractor equipment planted Coastal Bermuda grass at the rate of 1 acre per man day of labor in the spring of 1946. The sprigs used to plant the new area were grown in the nursery on the farm at a negligible cost. Sprigs were dropped in furrows opened by small shovels behind the tractor wheels and were covered with cultivators placed directly in front of the rear wheels of the tractor. These rear wheels packed the soil around the sprigs with the result that a very high percentage of them lived. The pasture was grazed lightly in 1946 and will be well sodded by the middle of 1947. Since the cost of the grass seed generally planted on an acre of pasture exceeds the cost of a man day of the labor used in this test, it would seem that the establishment of Coasttal Bermuda and other stoloniferous grasses by vegetative planting is entirely practicable. The fact that a number of farmers are planting Coastal Bermuda grass and that one has 160 acres well established lends weight to this statement.

CERTIFICATION

In the spring of 1946, the Georgia Crop Improvement Association began to certify sprigs of Coastal Bermuda grass. The only grower who could qualify according to the standards set up (8) sold 870,000 certified sprigs in 1946. These sprigs were separated and tied in bunches of 50 and were packed in lots of 1,000 in wet sawdust in tar paper lined burlap bags similar to those used for packing nitrate of soda. Sprigs packed in this manner were in good condition after 10 days in the package, indicating that they could be shipped a considerable distance.

DISCUSSION OF BREEDING METHOD

Little was known concerning the breeding behavior of Bermuda grass in 1937. Variation in Bermuda grass plants growing along a railroad right-of-way had been observed, suggesting that the species was naturally cross pollinated and that individual plants were heterozygous. So far as the writer could ascertain, however, no fundamental studies on the breeding behavior of Bermuda grass had ever been made.

In an effort to develop superior plants as rapidly as possible the breeding program was initiated by producing many hybrids between four good Bermuda grass clones. It was recognized that several thousand hybrids would be needed, assuming that the parents were heterozygous, and that very few could be made by tedious hand methods. Consequently the parent clones were interplanted so that natural crossing could occur. The results indicated that several thousand hybrids were produced in this manner. It was hoped that fundamental studies on breeding behavior might be conducted at the same time, but failure to obtain selfed seed delayed these studies several years.

It has been suggested that most workers would not consider making hybrids until naturally occuring variations had been studied. Certainly fundamental studies of the breeding behavior of any plant are important and often progress in the breeding of a species cannot be made until such studies are conducted. There are instances, however, such as the one related in this paper, when it may be desirable to digress from the more generally accepted breeding practices. It is the purpose of this discussion to show when, in the writer's opinion, such digression is justified.

The plant breeder hybridizes to combine desired characters and to obtain hybrid vigor. He studies variation and selects in order to isolate superior germ plasm. If the end product of a breeding program is to be propagated by seed, a certain amount of inbreeding is usually necessary and the breeding behavior of the superior selection must be understood. If the end product can be propagated vegetatively, the breeder need only be concerned with the most efficient method of producing a superior plant. In the latter case he will wish to combine in the superior plant all of the desired characteristics exhibited by the various sources of germ plasm at his disposal. He will also, in most cases, attempt to increase the yield by making those gene combinations which will impart the greatest amount of hybrid vigor to the offspring.

Any plant is capable of producing the same number and kind of gametes and homozygous inbred lines. It is possible, therefore, to obtain as many genotypically different hybrids by crossing two heterozygous plants as can be produced by crossing all of the homozygous inbred lines obtained from them. It is generally agreed that the amount of hybrid vigor that two homozygous inbred lines will impart to their hybrid can only be ascertained by making the cross and testing the resulting hybrid.

It is becoming increasingly evident that several years are required to evaluate adequately a single generation of a perennial grass. The 10 years required to develop a new variety of an annual cereal may easily become 20 or 30 years if the same procedure is followed in the development of a superior variety of a perennial grass. Any procedure, therefore, that will reduce the number of generations required to reach the desired end is worthy of consideration.

It seems evident that hybridization may well precede selection when the end product of a breeding program is a single superior plant that may be propagated vegetatively. Certainly more time will be consumed, more land will be required, and little if anything can be gained by selecting for one or more generations before hybrids are made. When hybridization does precede selection, and especially when the parents are believed to be heterozygous, thousands of hybrids should be produced and evaluated. If the species is naturally cross pollinated and difficult to hybridize by hand it may be desirable to depend upon natural crossing among the parent plants (the procedure described in this paper). In such cases the population should be increased to allow for the selfed plants that will probably occur.

The experience with Bermuda grass described in this paper demonstrates that superior plants can be developed by hybridization

and selection without a comprehensive knowledge of the breeding behavior of the species. If possible, however, some fundamental studies designed to reveal the breeding behavior of the species should be conducted at the same time that the crosses are being evaluated. Even after such information is available superior plants can be most efficiently produced by first hybridizing and then selecting within large numbers of F_1 hybrids.

SUMMARY

The evidence available indicates that Bermuda grass, *Cynodon dactylon*, is a highly cross-pollinated tetraploid having 36 somatic chromosomes and several fragments. Since Bermuda grass can be economically propagated by vegetative planting, a breeding program designed to produce superior clones was used. Making controlled Bermuda grass hybrids is extremely tedious and time-consuming. Consequently, the breeding program was begun with 5,000 seedlings from open-pollinated seed obtained from common, Tift, and two South African Bermudas that were interplanted in a crossing block.

Following one year's observations, 147 of the best of these clones, representing a range in types, were planted in 4 x 24 foot plots in triplicate. Over 50 observations were recorded for each plot from 1939 to 1946. Characteristics studied included rate of spread, sod density, frost resistance, disease resistance, yield, percentage weeds, percentage cover, seed yield and seed set, the interaction when grown with crimson clover and with Kobe lespedeza, root-knot-nematode resistance, and longevity. Striking differences in all measurements were observed. Other experiments were designed to compare the following features of a few superior clones: Fertilization requirements, chemical composition, palatability, and the yield and longevity when clipped to simulate close grazing.

Coastal Bermuda, one of the best of these clones, equals or surpasses the parents in all characteristics, makes good quality grass hay, and has produced nearly twice as much beef as common Bermuda grass when grazed. Station workers and farmers in the Southeast who have grown Coastal Bermuda report that it appears to be widely adapted and generally superior to common Bermuda. Coastal Bermuda grass sprigs are being certified by the Georgia Crop Improvement Association and a number of farmers are planting them.

LITERATURE CITED

1. AVDULOV, N. P. Karyo-systematische untersuchung der familie Gramineen. Albruss. Bot. Kong. Ber., 65–66. 1928.
2. BURTON, GLENN W. A useful seed blower for the grass breeder. Jour. Amer. Soc. Agron., 30:446–448. 1938.
3. ———. A cytological study of some species in the genus *Paspalum*. Jour. Agr. Res., 60:193–197. 1940.
4. ———. Coastal Bermuda grass. Ga. Coastal Plain Exp. Sta. Circ. 10. 1943.
5. ——— and SOUTHWELL, B. L. Cow cafeteria aids plant breeder in evaluating new grasses. Certified Milk, 18. 1943.
6. ———, MCBETH, C. W., and STEPHENS, J. L. The growth of Kobe lespedeza as influenced by the root-knot-nematode resistance of the Bermuda

grass strain with which it is associated. Jour. Amer. Soc. Agron., 38:651–656. 1946.

7. Hunter, A. W. S. A Karyosystematic investigation in the gramineae. Can. Jour. Res., 11:213–241. 1943.
8. Morrison, F. B. Feeds and Feeding. Ithaca, N. Y.: The Morrison Publishing Co. Ed. 20. 1936.
9. Official Handbook Georgia Crop Improvement Association. Georgia Ext Service Pub. Athens, Ga. 1946.

Inheritance of Resistance in Alfalfa to Bacterial Wilt[1]

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BACTERIAL wilt caused by *Corynebacterium insidiosum* (McCull.) Jensen, has become the most serious disease of alfalfa in California and in this country. It annually destroys hundreds of thousands of acres of alfalfa (9)[3] and resistant varieties appear to be the only effective means of control. In the search for resistant strains seed collections from all over the world were tested at the Kansas, Nebraska, Wisconsin, and California agricultural experiment stations in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture (1,3,7,10). Hairy Peruvian and California Common, the principal varieties grown in California, as well as most of the other American varieties, including Grimm, Baltic, Hardigan, Canadian Variegated, and the Common group, were susceptible. Cossack, Ladak, and American Turkestan were partially resistant. Seed lots from Turkestan and part of those from other regions of Asia contained resistance, though the amount varied. Alfalfa from the rest of the world was for the most part susceptible. Selection has resulted in the new varieties Hardistan, Orestan, Kaw, Ranger, and Buffalo which possess resistance (4,5,7).

Resistance to bacterial wilt is inherited, but selected plants differ greatly in their ability to transmit resistance to their selfed progeny. Progenies range from those with only a few to those with all healthy plants (1,3,10). No true-breeding resistant plants have been identified. Brink, Jones, and Albrecht (1), after selfing Hardistan plants, concluded that the genetic basis for resistance was complex. They also observed segregation in the F_2 of crosses between resistant and susceptible plants, but a factorial interpretation was impossible.

All the varieties and strains containing resistance are winter dormant, which is objectionable in California because growth is retarded early in the fall and delayed in the spring. These genetic studies were undertaken to provide the basis for utilizing this resistant material in breeding a suitable alfalfa for California. Artificial inoculation was used throughout. Data are presented for the selfed progeny of a few resistant plants and for crosses between these plants and the susceptible California Common.

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[2]Formerly graduate assistant, Division of Agronomy, University of California. The author is indebted to Dr. F. N. Briggs, Professor of Agronomy, who gave generously of his time as consultant and advisor throughout the course of these studies. Thanks are also due to other members of the Agronomy Division for their aid. The Division of Plant Pathology generously supplied cultures of the pathogen whenever needed.

[3]Figures in parenthesis refer to "Literature Cited", p. 582.

MATERIALS AND METHODS

The resistant lines, mostly of Turkestan origin, used in these investigations came from the selection work started by Weimer and Madson (10) and continued by Madson. While selfed progenies were grown from many of these selected plants, data are reported for only nine. These were also crossed with the susceptible California Common and the F_1, F_2, and some F_3 grown. Some reciprocal crosses were made and two F_1 plants were backcrossed to California Common. The data are from two plantings in 1942 and one in 1943.

The original hybridizations were made using the suction method of emasculation. Later a combination of the suction method and the alcohol method (6) was employed. All seed was produced on potted plants growing in a screened greenhouse. In selfing the flowers were tripped by hand, cleaning the hands with alcohol between plants. The well known self-sterility of alfalfa proved quite a handicap. The plants in only one of nine F_2 families chosen for selfing were fertile enough to permit a progeny test of most of the plants. All F_1, F_2, and backcross plants that were selfed were uninoculated. The seed was planted outdoors in cold frames or in field nurseries, and the seedlings dug for inoculation in May and June when 3 to 5 months old. Cuttings of plants were made in January and February, and rooted in sand in the greenhouse.

INOCULATION

The causal organism, *Corynebacterium insidiosum* (McCull.) Jensen, was grown in broth cultures, using 150 cc of broth in 500 cc flasks. New isolates were used each year. For inoculation 2- to 4-day old cultures of three different isolates were mixed in equal amounts, and 450 cc of this mixture added to 2 liters of water in a shallow pan. Each pan of bacterial suspension was used to inoculate 800 to 1,200 plants. The large amounts of culture were used in an attempt to secure 100% infection of susceptible plants.

Inoculation was by the same general method used by other investigators (1,2,3, 10). The seedlings were dug, taking care to obtain at least 6 inches of taproot, and throughly washed. They were then inoculated by cutting off the ends of the taproots under the bacterial suspension. While in the inoculum the taproots were also lightly scraped with a knife. In the May 1942 and the 1943 plantings the tops were also cut off and the cut ends dipped into the inoculum. Though the plants from cuttings had very small roots, they were inoculated in the same general way. Either immediately after inoculation or early the next morning the plants were set in the field 6 inches apart in 3-foot rows. Throughout the summer the alfalfa was irrigated frequently to keep it growing vigorously. Except for the June 1942 planting the tops were cut once.

CLASSIFICATION

The alfalfa plants were classified for bacterial wilt in the fall after the disease was well developed but before the susceptible plants had died (usually 4 to 5 months after inoculation). Classification was based on discoloration in the taproot which was determined by cutting across the taproot with a sharp knife. Plants were classified as healthy or one of three degrees of diseased. Class O contained healthy plants whose taproots were white and had no discoloration. In class 1 the yellow-brown discoloration was slight and only occurred in small areas as seen in cross section or streaks in longitudinal section, while in class 2 the discoloration was well developed but limited to part of the area of the taproot as seen in cross section. Class 3 included severely diseased plants whose taproots were extensively discolored like those from typical diseased plants of the susceptible California Common. The four classes are illustrated in Fig. 1. These descriptions are based on material inoculated artificially as described previously.

The percentages are based on the number of plants at the time of classification. In the material studied, the values of classes 0 and 3 ranged from 0 to 100, while the values of classes 1 and 2 ranged from 0 to 40%. Classes 0 and 3 can be used to represent a population, and in some cases only class 0 is reported. Most of the data are from the May 1942 and the 1943 plantings when the level of infection was high, but some are from the June 1942 planting when the level was somewhat low. The susceptible check had 2% class 0 and 92% class 3 under the high level of

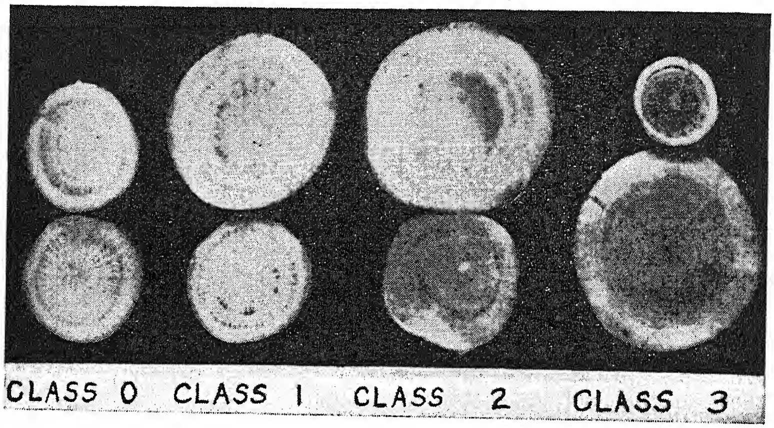

FIG. 1.—Cross sections of alfalfa taproots from artificially inoculated material illustrating the classification scheme. Plants of class 0 are healthy, class 1 contains slightly diseased plants, class 2 moderately diseased plants, and class 3 severely diseased plants. ×1.5

infection, and 7% class 0 and 75% class 3 under the lower level. The check rows indicated that both levels of infection were uniform. Thirty F_2 and resistant inbred populations ranging from susceptible to highly resistant were also tested under both conditions. There was some increase in the proportion of healthy plants (class 0) under the lower level of infection; however, the main difference was a decrease in severely diseased plants (class 3) and an increase in slightly and moderately diseased plants (classes 1 and 2). When the percentage of plants in class 0 for each of the populations under low infection was compared with that for the same population under high infection, the relationship was found to be linear. The same held true for the values of class 3. Therefore a regression coefficient was calculated for each of these classes and the coefficient used to adjust the data from the June 1942 planting, making it directly comparable to the other data. Some error is introduced and therefore the adjusted data are marked.

EXPERIMENTAL RESULTS

SUSCEPTIBLE CHECK

The same seed lot of California Common alfalfa was used throughout these investigations as the susceptible check. Weimer and Madson (10) had previously shown this variety to be completely susceptible. In the May 1942 and the 1943 plantings there was the same high level of infection (Table 1). The check was planted about every twelfth row and a chi-square test for the check rows in these years

TABLE 1.—*Wilt reaction of California Common the susceptible check.*

Planting	Number of plants	Percentage			
		Class 0	Class 1	Class 2	Class 3
1942 May	666	2.1	2.0	4.2	91.7
1943	1,089	1.6	2.7	4.4	91.4
1942 June	1,187	2.0	—6.0—	—6.0—	92.0*

*Adjusted to the same level of infection as the other data. (See under Materials and Methods.)

gives no evidence against homogeneity, indicating a uniform level of infection. While over 91% fell in class 3, a few check plants even though susceptible remained healthy (class 0), and in others the disease failed to develop extensively (classes 1 and 2). In the June 1942 planting the level of infection was lower but still uniform. As explained above these data were adjusted to the same level of infection as the other plantings.

SELFED PROGENY OF RESISTANT AND SUSCEPTILE PLANTS USED AS PARENTS IN CROSSES

Selfed progenies were grown from about 75 of the plants selected by Madson and Weimer. None were susceptible, but the progenies ranged from those with only a few to those with all healthy plants. This wide range is similar to that reported by other workers (1,3,10). The results from the selfed progeny of the nine resistant plants used in crosses with the susceptible California Common are given in Table 2.

TABLE 2.—*Wilt reaction of the selfed progeny from the resistant and susceptible plants used as parents in crosses.*

Parent plant	Selfed progeny		
	Number	Percentage	
		Class 0	Class 3
Resistant			
Kansas Common selection 121–1	21	66	6*
Kansas Common selection 121–2	27	74	13*
Turkestan selection 132–1	26	88	0
	48	80	4*
Turkestan selection 132–2	54	68	24
	97	49	34*
Turkestan selection 132–3	24	79	4
	52	76	4*
Turkestan selection 134–1	40	100	0*
Turkestan selection 141–1	61	90	2
	98	86	6*
Turkestan selection T-13–1	32	75	0
	44	88	4*
Turkestan selection T-13–2	84	70	2
	88	82	6*
Susceptible			
California Common C-1	161	4	93*
California Common C-4	56	0	100
California Common C-5	110	1	98
California Common C-8	84	10	90*

*Adjusted to the same level of infection as the other data. (See under Materials and Methods.)

Seven of the progenies had about 80% healthy plants (class 0). Turkestan selection 132–2 had fewer and Turkestan selection 134–1 had more than this percentage of class 0 plants. The selfed progeny of the California Common plants used as the susceptible parents (Table 2) behaved like the susceptible check.

In four of the resistant lines, S_1 plants classified as types 0 and 1 were saved for selfing. The wilt reaction of their progeny is given in Table 3. The progenies of even these selected S_1 plants tracing to Turkestan selections 132–2, 134–1, and T–13–2 covered the whole range from low to high resistance. Though all the S_2 families from Turkestan selection 141–1 are highly resistant, a chi-square test shows they are not a homogeneous group. The data as a whole suggest that several genes probably control the inheritance of resistance to wilt, and that at least part of the plants used as the resistant parents in crosses are not homozygous.

TABLE 3.—*Percentage of plants in class 0 for the S_2 generation of a sample from S_1 plants classified as types 0 or 1.*

Parent plant	Number of S_1 plants	S_2 generation										
		Av. No. plants per family	Number of families with indicated percentage									
			5	15	25	35	45	55	65	75	85	95
Turkestan selections:												
132–2	10	71	2*	1	1	1	1	–	–	1	2	1
134–1	16	68	3*	1	–	–	2	1	3	2	3	1
141–1	13	61	–	–	–	–	–	1	1	3	2	6
T-13–2	13	87	1*	1	–	1	–	2	1	–	4	3

*These differed sufficiently from the check based on the percentage of plants in class 3 to be considered as having a weak resistance.

F_1 AND F_2 OF CROSSES BETWEEN RESISTANT AND SUSCEPTIBLE

Five F_1 populations were inoculated (Table 4). If the resistant parents are not true-breeding, then the F_1 will consist of a mixture of genotypes. The results show not only that these five resistant parents differ greatly in the basis for their resistance, but that in general resistance tends to be dominant to susceptibility.

Several uninoculated F_1 plants from each cross were selfed and the progeny of each plant kept separate. The wilt reaction of these F_2 families is given in Table 5. All families contained over 65 plants and one-third had over 150. Taken together the families covered the whole range from susceptible to highly resistant. Several of the susceptible progenies came from crosses where the resistant parent was the female, and two of the highly resistant progenies came from crosses where the susceptible parent was the female. This and the fact that the F_1 plants were entirely different from the selfed progeny of the parents shows that the F_1 plants were actual hybrids. The separation of the susceptible from weakly resistant families was based

TABLE 4.—*Wilt reaction of the F_1 from certain crosses between resistant and susceptible.*

Cross	F_1 plants		
	Number	Percentage	
		Class 0	Class 3
Kansas Common sel. 121–2 × Calif. Common	39	19	40*
Turkestan selection 132–3 × Calif. Common	40	0	51*
Turkestan selection 134–1 × Calif. Common	60	79	7*
Turkestan selection 141–1 × Calif. Common	30	70	4*
Turkestan selection T-13–1 × Calif. Common	26	36	14*

*Adjusted to the same level of infection as the other data. (See under Materials and Methods.)

on a comparison of the percentage of plants in class 3 with that for the check. Too few F_2 families were studied from any cross to determine how many types of F_1 plants there were or their relative frequency. However, the presence of susceptible F_2 families (Table 5) means that Turkestan selections 132–1, 132–2, and 132–3 are heterozygous for all their genes for resistance. The wide range of the F_2 families tracing to Turkestan selections 132–1 and 141–1 and to Kansas Common selection 121–2 indicates that these plants contain at least two genes for resistance.

ISOLATION OF SINGLE GENES FOR RESISTANCE

When F_2 families were classified no grouping into definite classes was observed, and therefore it was impossible to determine how many genes were segregating in any one family. This condition is frequently encountered in genetic studies of disease resistance, and the common

TABLE 5.—*Percentage of plants in class 0 for F_2 families from crosses between resistant and susceptible.*

Cross	Number of F_1 plants	Number of F_2 families with indicated percentages*									
		5	15	25	35	45	55	65	75	85	95
Kan. sel. 121–1 × Calif. Com.	6	4†	1	1	–	–	–	–	–	–	–
Kan. sel. 121–2 × Calif. Com.	4	–	1	–	1	–	1	1	–	–	–
Turk. sel. 132–1 × Calif. Com.	6	1‡	–	1	2	–	–	2	–	–	–
Turk. sel. 132–2 × Calif. Com.	3	1‡	1	–	1	–	–	–	–	–	–
Turk. sel. 132–3 × Calif. Com.	3	2‡	–	–	–	1	–	–	–	–	–
Turk. sel. 134–1 × Calif. Com.	3	–	–	–	–	–	–	1	–	1	1
Turk. sel. 141–1 × Calif. Com.	8	–	1	1	2	1	–	1	1	1	–
Turk. sel. T-13–1 × Calif. Com.	3	–	–	–	–	–	3	–	–	–	–
Turk. sel. T-13–2 × Calif. Com.	1	–	–	1	–	–	–	–	–	–	–

*About two-fifths of the families were adjusted to the same level of infection as the other data. (See under Materials and Methods.)

†These differed sufficiently from the check based on the percentage of plants in class 3 to be considered as having a weak resistance.

‡These are sufficiently like the California Common check to be considered as homozygous susceptible.

practice is to classify F_2 and backcross plants by their selfed progeny. Many of the nine F_2 and two backcross families chosen were eliminated because of the self-sterility of most of their constituent plants. Other losses occurred leaving two F_2 and one backcross family.

Because many F_2 plants were sterile and since alfalfa can be vegetatively propagated, it was decided to increase each F_2 plant vegetatively to 5 to 10 plants and inoculate them. Thus the classification of each F_2 plant would be based on the reaction of several plants of the same genotype instead of on a single individual. To orient this method it was tried on the plants of one F_2 and one backcross family which were also being progeny tested.

1. *F_1 plant N24–C, from the cross of Turkestan selection 132–3 × California Common.*—Selfed progenies of 42 F_2 plants were inoculated. The F_3 families which averaged 30 plants each fell into two groups with 35 in the resistant and 7 in the susceptible. Forty F_2 plants (36 were progeny tested, 4 were self-sterile) were successfully propagated vegetatively. The clones averaged six plants each. The reaction of these clones divided the F_2 plants into 31 resistant and 9 susceptible. For the 36 plants classified both by progeny and by clones, the results from the two methods were consistent. Of the four plants studied only as clones, one was resistant and three were susceptible. Combining the data from clones and selfing there were 36 resistant and 10 susceptible F_2, indicating segregation for a single dominant gene.

The 268 F_2 plants grown gave 41, 18, 13, and 28%, respectively, in classes 0, 1, 2, and 3. These values represent the combined effects of gene segregation, the phenotypic expression of the genotypes, and the level of infection. Therefore 41% in class 0 is the best estimate of the expected proportion for that class in a segregating F_3 family. Applying the standard deviation, $\sqrt{\frac{p\,q}{n}}$, based on 41% in class 0, to the 35 resistant F_3 families, 10 were found to have a value for class 0 greater than the 5% limit. Most of these 10 exceeded the 1% limit. This is close to the one-third of these families that would be homozygous for resistance on the basis of segregation for one gene. If this gene is designated P, then on the basis of the F_3 families the F_2 plants are grouped into 10 PP, 25 Pp, and 7 pp (Fig. 2). Of course the separation of PP from Pp is only approximate. The weighted averages for all the families in each group are given in Table 6.

Table 7 gives the averages for clones of the three genotypes, the clones from all F_2 plants of the same genotype having been averaged. The reaction of clones from individual PP and Pp plants is very similar, and therefore the separation of these two genotypes was based on their selfed progeny. Just why the PP and Pp genotypes were more resistant as clones (Table 7) than as seedlings (Table 6) is not known. The clonal plants were somewhat difficult to classify because of small roots.

2. *F_1 plant N20–A, from the cross of Turkestan selection 132–1 × California Common.*—This F_1 plant was backcrossed to California Common. Selfed progenies and clones were obtained from most of

TABLE 6.—*Summary of the wilt reaction of selfed progeny from F_1, F_2, and backcross plants of certain genotypes.*

F_1 plants*	Parents		Selfed progeny				
	Generation	Genotype	Number of plants	Percentage			
				Class 0	Class 1	Class 2	Class 3
N24-C	F_1	Pp	268	41.0	17.9	12.7	28.3
	F_2	PP	321	71.6	13.7	6.9	7.8
		Pp	758	38.1	16.1	16.5	29.3
		pp	161	1.9	0	1.2	96.9
N20-A	F_1	RrTt	—	—	—	—	—
	Backcross	RrTt	364	35.2	19.8	18.7	26.4
	(N20-A	Rrtt	248	17.7	17.7	21.4	43.1
	×	rrTt	281	3.2	5.7	16.0	75.1
	Calif. Com.)	rrtt	235	0.4	0.9	1.3	97.4
N10-B	F_1	T′t′	92	3.3	7.6	26.1	63.0
	F_2	T′T′	123	17.1	24.4	19.5	39.0
		T′t′	239	5.0	11.7	20.1	63.2
		t′t′	95	0	0	9.5	90.5
California Common check.........			—	1.6	2.7	4.4	91.4

*F_1 plant N24-C is from the cross of Turkestan sel. 132-3 × Calif. Com.; F_1 N20-A is from the cross of Turkestan sel. 132-1 × Calif. Com.; and F_1 N10-B is from the cross of Kansas Common sel. 121-1 × Calif. Com.

the backcross plants, but unfortunately about half the progenies were in a plot where the level of infection was low.

Progenies of 26 backcross plants, averaging 43 plants, were studied under a high level of infection in 1943. The percentage of plants in class 0 more or less clearly divided the families into two groups. The percentage of plants in class 3 confirmed this split and furthermore

TABLE 7.—*Summary of the wilt reaction of clones from F_2 and backcross plants of the same genotype.*

F_1 plants	Source of clones		Number of plants	Percentage			
	Generation	Genotype		Class 0	Class 1	Class 2	Class 3
N24-C	F_2	PP	66	100	0	0	0
		Pp	121	92	7	0	1
		pp	51	6	0	4	90
N20-A	Backcross	RrTt	59	59	26	15	0
	(N20-A	Rrtt	55	46	22	25	7
	×	rrTt	44	0	7	27	66
	Calif. Com.)	rrtt	52	0	0	2	98
California Common.....		Susc.	54	0	2	2	96

suggested that each of these groups was also divided into two parts. Four approximately equal classes suggests that the F_1 was heterozygous for two independent genes for resistance. If they are designated R and T, then the genotypes of the backcross plants and their frequencies are RrTt–9, Rrtt–6, rrTt–5, and rrtt–6 (Fig. 3). The progenies of RrTt and Rrtt overlap and the separation is only approximate. The average reaction of the progeny of the four backcross genotypes is given in Table 6. Twenty-three of these backcross plants were also inoculated as clones averaging 7 plants each. These fell into a resistant group of 13 and a susceptible group of 10. A comparison with the selfed progenies showed that the resistant group as determined by the clones contained the RrTt and Rrtt plants, and the susceptible group contained the rrTt and rrtt plants. The averages for clones from the four genotypes are given in Table 7, the separation of RrTt from Rrtt and rrTt from rrtt having been based on their selfed progenies.

The progenies of an additional 21 backcross plants were grown in a plot where for some unknown cause the level of infection was low. The percentage values for classes 0 and 3 divided the families into 7

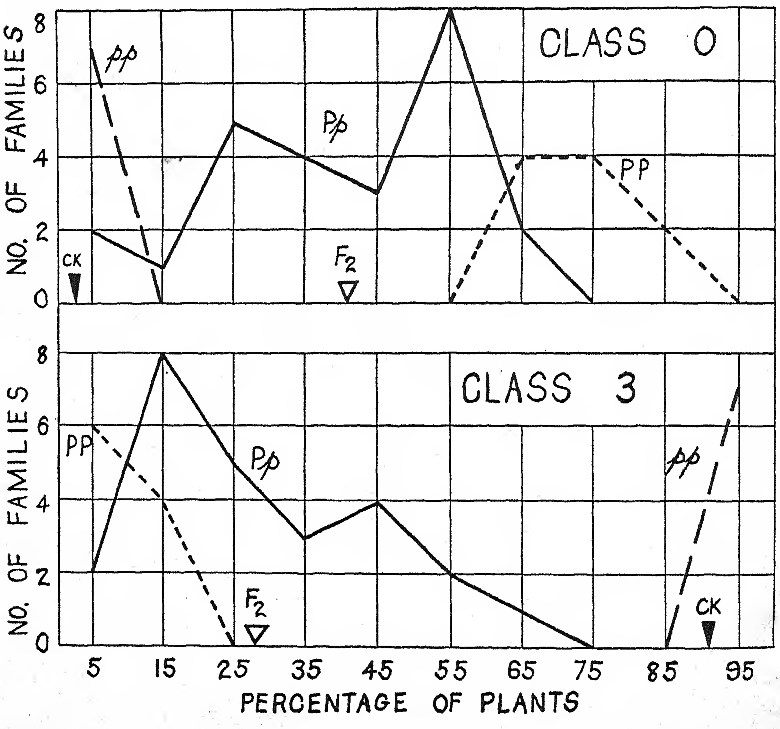

FIG. 2.—Wilt reaction of 42 F_3 families tracing to F_1 plant N24–C. The F_2 genotypes are indicated, and the percentage of plants in class 0 and in class 3 are given for each family. The reaction of the susceptible check (CK) and of the F_2 of N24–C are also given.

resistant, 11 intermediate, and 3 susceptible (Fig. 4). The F_2 of N20–A gave the same reaction as the most resistant group. Some of the backcross plants were also studied as clones which fell into two about equal classes, resistant and susceptible. The clones agreed with the resistant and susceptible groups of the selfed progenies. Part of the clones of plants of the intermediate group were resistant and part were susceptible. Therefore, these 21 backcross plants also consist of four types about equal in number.

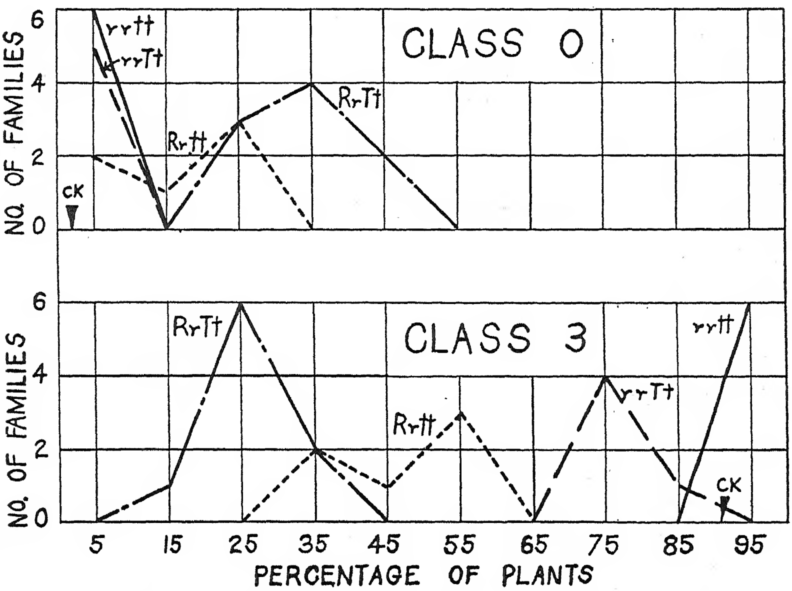

FIG. 3.—Wilt reaction of the selfed progeny of 26 backcross plants from F_1 plant N20–A; high level of infection. The genotypes of the backcross plants are indicated, and the percentage of plants in class 0 and in class 3 are given for each of the families.

Combining the two levels of infection and considering only the selfed progenies there were 16 resistant, 22 intermediate, and 9 susceptible backcross plants. The 35 plants classified both by clones and by their selfed progeny consisted of 10 RrTt, 8 Rrtt, 9 rrTt, and 8 rrtt. Therefore, F_1 plant N20–A is heterozygous for two independent, partially dominant, supplementary genes for resistance. The T gene is quite weak.

3. *F_1 plant N10–B, from the cross of Kansas Common selection 121–1 ×California Common.*—Because of sterility only 18 F_3 families averaging 25 plants each were obtained. Their wilt reaction suggested that F_1 plant N10–B was heterozygous for a single weak gene for resistance. This gene was designated T′. The weighted averages for the progenies of F_2 genotypes T′T′, T′t′, and t′t′ are given in Table 6. Judging by the families segregating for this gene, it is very similar to the T gene isolated from F_1 plant N20–A.

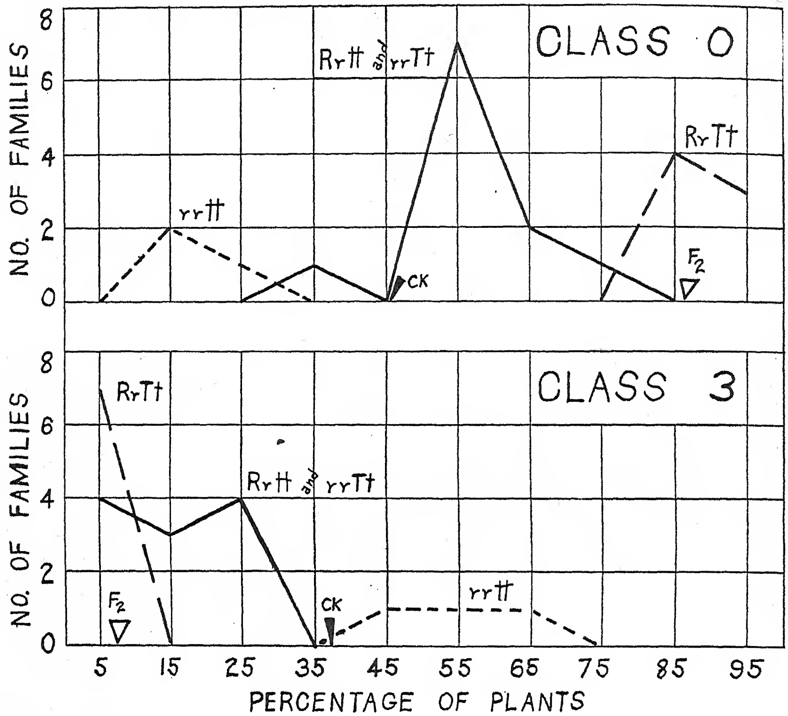

FIG. 4.—Wilt reaction of the selfed progeny of 21 additional backcross plants from F_1 plant N20–A; low level of infection. The genotypes of the backcross plants are indicated, and the percentage of plants in class 0 and in class 3 are given for each family. The reaction of the F_2 of N20–A, and of the check (CK) are also given.

GENOTYPE REACTION

Since environment greatly influences the reaction of alfalfa to the pathogen, all parts of the testing procedure were standardized as

TABLE 8.—*Wilt reaction of eight clonal lines.*

Plant	Number per clone	Percentage			
		Class 0	Class 1	Class 2	Class 3
Turkestan selection 141–1	116	100	—	—	—
Turkestan selection T-13–2	110	100	—	—	—
F_1 N20-A* (RrTt)	107	95	5	—	—
F_1 N20-B*	95	84	12	4	—
F_1 N10-B† (T'_t')	58	7	5	12	76
F_1 N11-A‡	104	73	26	1	—
Susceptible No. 49	70	—	1	1	98
Susceptible No. 50	92	2	—	9	90

*F_1 plants N20-A and N20-B are from the cross of Turkestan Sel. 132-1 ×Calif. Common.
†F_1 N10-B is from the cross of Kansas Common sel. 121-1 ×Calif. Common.
‡F_1 N11-A is from the cross of Kansas Common sel. 121-2 ×Calif. Common.

closely as possible. However, preliminary data suggested that some resistant genotypes probably varied widely in their wilt reaction. Pure lines were not available, but vegetative propagation offered an ideal means of studying this problem and large clones from eight plants were inoculated in 1943 (Table 8). All the plants in the clones from Turkestan selections 141–1 and T–13–2 were healthy, while the clones from susceptible plants 49 and 50 behaved like the California Common check. Plants from the clones of N20–A, N20–B, N10–B, and N11–A fell into two, three, and even all four classes. Therefore it must be concluded that even in the limited environment in which the tests were conducted that the phenotypic expression of a single genotype may vary widely.

DISCUSSION

The R and T genes isolated in F_1 plant N20–A came from Turkestan selection 132–1, the P gene isolated in F_1 plant N24–C came from Turkestan selection 132–3, and T′ isolated in F_1 plant N10–B came from Kansas Common selection 121–1. These genes have not been intercrossed, but their behavior in segregating families (Table 6) suggests that P, R, and T are different. Furthermore Turkestan selections 132–1 and 132–3 are both inbred progeny of Turkestan selection 132. Therefore, P, R, and T all trace to the single plant, selection 132, which was selected by Weimer and Madson (10) from Seed and Plant Introduction No. 20988. All four genes are partially dominant and R and T are supplementary in action. P is the strongest and R is intermediate, while T and T′ are both weak. More data are needed to complete the description of these genes, and only a start has been made in determining the genetic basis for resistance in even plant selections 132–1, 132–3, and 121–1 from which these four genes were obtained. Further work might uncover still others.

The similarly behaving T and T′ came from unrelated plants, and it has not been determined whether they are identical. F_2 families from the other resistant parents (Table 5) suggest that they contain genes either similar to or identical with P, R, and T. The F_2 families with more than 40 to 50% healthy plants may be segregating for a gene stronger than P, or may prove to be segregating for several genes. The situation is further complicated by plants of different genotypes whose selfed progeny have about the same percentage of plants in the four classes. For instance, the progenies of RrTt and Pp appear alike, as do the progenies of T′T′ and Rrtt (Table 6).

The presence of several genes differing in strength of resistance will explain the great variation found on selfing alfalfa plants. Resistant varieties like Hardistan contain some completely susceptible plants (determined by progeny testing). Since alfalfa is largely cross pollinated (8), such a variety will then contain a mixture of many different genotypes with regard to wilt resistance.

In families segregating for any one of the genes isolated there was no grouping of plants into definite classes, but a continuous variation from healthy to severely diseased. Even plants of F_3 families homozygous for P and T′ behaved the same way. Some of this variation may be due to the segregation of modifying factors. However, clones

of single plants have indicated that much of it is phenotypic variation of a genotype.

If F_1 plants contain several genes for resistance, then analyzing them by backcrossing to California Common and selfing the backcross plants will be easier than growing the F_2 and F_3. Not only are there less genotypes, 2^n as against 3^n, but this method also eliminates much of the trouble caused by self-sterility. Backcross plants are usually much more self-fertile than F_2 plants. It is advantageous to backcross to California Common plants other than those used in the original crosses. Clonal lines containing 5 to 10 plants offer a means of classifying self-sterile plants. Clones separated PP and Pp plants from pp plants and Rr from rr plants. However, clones of this size would not separate the weakly resistant Tt from tt. Therefore, the usefulness of this method will depend on the genotypes to be separated.

Where wilt is prevalent stands of susceptible varieties like Grimm and California Common are killed out in three to five years, while stands of resistant varieties like Hardistan and Ranger are still good after six years or more. Since these single genes have just been isolated they have not been grown alongside Hardistan or Ranger. However, in a previous test in California (10), Hardistan gave 18 to 19% healthy against 1 to 5% for California Common (data from one inoculation only). At Nebraska from 1929 to 1938 Hardistan averaged 48% and Grimm 5% healthy (7). In later experiments at Nebraska and Wisconsin Hardistan gave 19%, Ranger 37%, and Grimm 3% healthy plants (11). Therefore it is believed that the P factor, which in the homozygous condition had 72% healthy plants, will provide adequate protection against bacterial wilt and can be used to breed a wilt-resistant alfalfa for California or elsewhere.

SUMMARY

1. Data are presented demonstrating that the resistance of alfalfa to bacterial wilt can be resolved into terms of separate genes. Three and possibly four partially dominant genes differing in strength of resistance were isolated.

2. The available data suggest that one of these, the P gene, will give adequate protection against bacterial wilt, and that it can be used to breed resistant varieties. Homozygous P gave 72% healthy, 20% intermediate, and 8% severely diseased plants. In comparison, the susceptible California Common gave 2% healthy, 7% intermediate, and 91% severely diseased plants.

3. Clones from individual plants demonstrated that a single genotype might vary from healthy to severely diseased even under rather uniform conditions.

4. Inoculating clones containing 5 to 10 plants is a promising method of identifying self-sterile F_2 or backcross plants as resistant or susceptible.

LITERATURE CITED

1. BRINK, R. A., JONES, F. R., and ALBRECHT, H. R. Genetics of resistance to bacterial wilt in alfalfa. Jour. Agr. Res., 49:635–642. 1934.
2. JONES, F. R. Artificial inoculation of alfalfa to determine susceptibility to bacterial wilt. Rpt. 8th alfalfa improvement conf., Div. Forage Crops and Diseases, U.S.D.A., 10–14. 1940 (Mimeographed)

3. PELTIER, G. L., and TYSDAL, H. M. Wilt and cold resistance of self-fertilized lines of alfalfa. Neb. Agr. Exp. Sta. Res. Bul. 76:1–26. 1934.
4. SALMON, S. C. Kaw—A new alfalfa. Jour. Amer. Soc. Agron., 24:352–353. 1932.
5. TYSDAL, H. M. 1942 report of the uniform advanced alfalfa nurseries. Division of Forage Crops and Diseases, U.S.D.A. 1943. (Mimeographed)
6. ——————, and GARL, J. RUSSELL. A new method for alfalfa emasculation. Jour. Amer. Soc. Agron., 32:405–407. 1940.
7. ——————, and KIESSELBACH, T. A. Alfalfa in Nebraska. Neb. Agr. Exp. Sta. Bul. 331:1–68. 1941.
8. ——————, ——————, and WESTOVER, H. L. Alfalfa breeding. Neb. Agr. Exp. Sta. Res. Bul. 124:1–46. 1942.
9. ——————, and WESTOVER, H. L. Alfalfa improvement. U.S.D.A. Yearbook of Agriculture, 1937: 1122–1153. 1937.
10. WEIMER, J. L., and MADSON, B. A. Relative resistance to bacterial wilt of certain commercial and selected lots of alfalfa. Jour. Agr. Res., 52:547–555. 1936.
11. WESTOVER, H. L. Rpt. 9th alfalfa improvement conf., Div. Forage Crops and Diseases, U.S.D.A. 1942. (Mimeographed)

Effect of Grazing Management on Beef Gains from White Clover-Grass Pastures in Central Alabama[1]

E. L. MAYTON, J. C. GRIMES, AND H. T. ROGERS[2]

EXTENSIVE fertilizer tests with white clover, *Trifolium repens*, in combination with various summer grasses had shown as early as 1934 (8)[3] that this clover could be grown successfully in permanent pasture sods in most of the major soil provinces of Alabama.

White clover has long been recognized as the most important perennial legume in pastures in the northeastern part of the United States and in Canada, as well as in other countries with cool-humid climates. In the sub-tropical climate of the Gulf States, however, this plant tended to act more as an annual than a true perennial, particularly on sandy soils. This was a distinct disadvantage, since the growth of clover was delayed each spring when the new crop had to come from seedlings.

From observations of white clover-grass pastures in various section of the state, it appeared that the method of grazing of white clover might be an important factor in determining its behavior, thereby affecting the amount of high protein pasturage obtained. It appeared logical that management might be very important on areas where many of the plants died each summer and the following year's growth depended to a large extent on a seed crop and new seedlings each spring.

GENERAL OBJECTIVE

A grazing experiment in which beef gains by brood cows and calves were used to measure the effects of different systems of grazing on white clover survival was started on the Animal Husbandry section of the Alabama Agricultural Experiment Station, Auburn, in the fall of 1941. One of the major objectives of the study was to determine the effect of controlled grazing on the production of a seed crop by white clover, as it was assumed that under heavy grazing this legume would not mature sufficient seed to maintain a stand. Also it was desired to find out what effect rotated and controlled grazing had on the survival of this clover as a true perennial plant under the climatic and soil conditions prevailing in this area.

SYSTEMS OF GRAZING STUDIED

The four methods of grazing that were employed on the white clover-grass bottom land pastures were:

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[2]Superintendent of the Piedmont Substation (formerly Associate Agronomist), Head of the Animal Husbandry Department, and Associate Soil Chemist, respectively. The manuscript was prepared by the second junior author who is now Agronomist with the Tennessee Valley Authority.

[3]Figures in parenthesis refer to "Literature Cited", p. 594.

No. 1, Continuous and heavy stocking

No. 2, Rotated grazing at a moderate rate of stocking (grazed 2 weeks and rested 4 weeks)

No. 3, Continuous and moderate stocking

No. 4, Moderate stocking with no grazing during May to allow clover to mature seed crop

An upland area (primarily hop clover-Bermuda grass sod) that was moderately stocked was designated as pasture No. 5.

The actual average rates of stocking are shown in Table 1 along with data on the average annual production of beef under the different systems.

EXPERIMENTAL SET-UP AND TECHNIQUES

DESCRIPTION OF THE AREA

An area of bottom land (Fig. 1), which is fairly representative of the alluvial flood plains along the creeks of the Upper Coastal Plains Province in Central Alabama, was selected for the four grazing paddocks on which different management systems were studied. The soil on these bottom lands is best described as undifferentiated alluvium, consisting of a heterogeneous mixture of materials (7) subject to periodic overflow from the stream. The soil on this area (32 acres), which consists largely of sands and loamy sands, is of low to medium fertility and is quite variable in texture and drainage. About the same amount of sloping land at the foot of adjacent slopes was included in each pasture. The soil on the surrounding slopes was predominantly Chesterfield sandy loam (7).

A sketch of the plot layout showing the relative position of the several grazing paddocks, including an adjoining hillside pasture on which weight records were

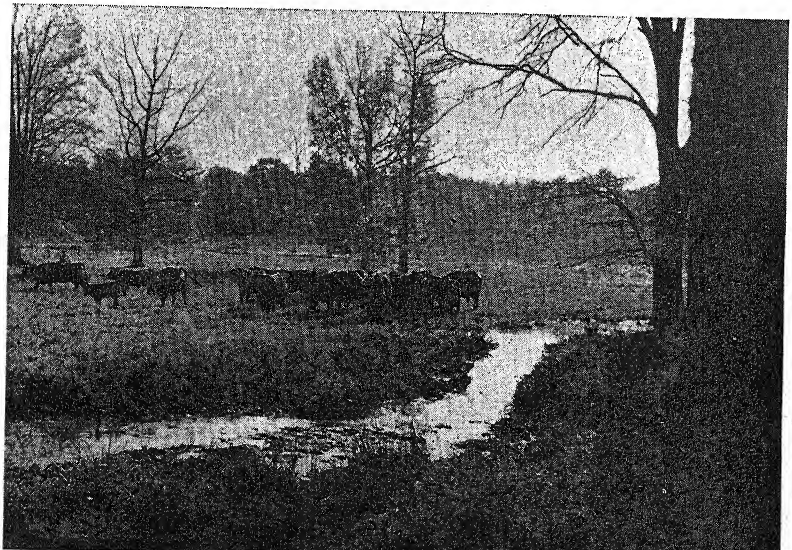

FIG. 1.—Shown here is the herd of Aberdeen Angus cattle used in this study on one of the bottom land pastures, which is representative of the alluvial flood plains along the streams in the Upper Coastal Plains Province of central Alabama. Photographed Nov. 30, 1946.

kept for comparison, is shown in Fig. 2. The four bottom land paddocks were each 8 acres in size. Plot 2, which was used for rotational grazing, was divided into three sub-paddocks. The hillside pasture (8.7 acres) was typical of the eroded sandy slopes of this section and was extremely low in fertility at the outset of the experiment. The soil is Chesterfield sandy loam. This area had been an unimproved common Bermuda grass pasture for several years following a period of row-cropping. The bottom land had been an unimproved native carpet grass pasture for a number of years previous to the start of the grazing experiment.

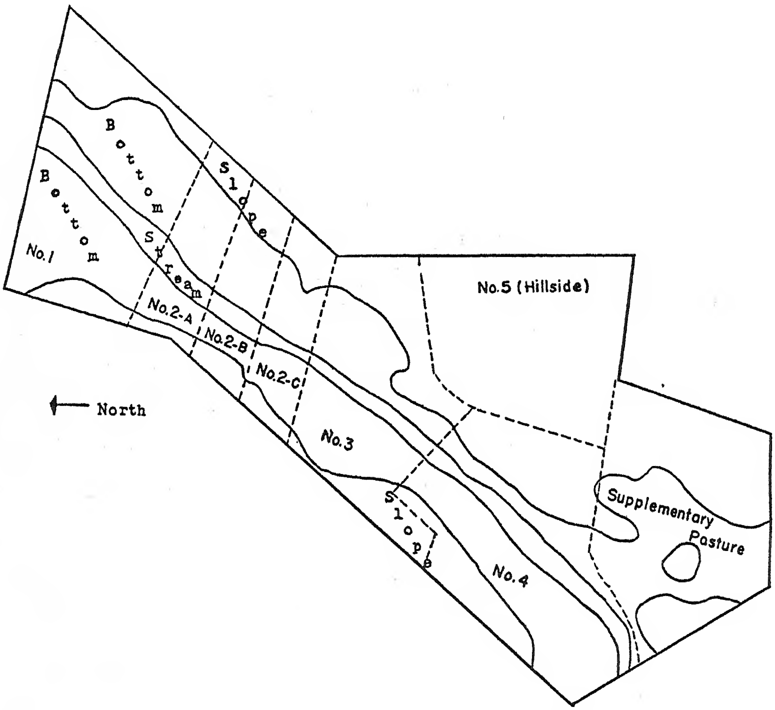

FIG. 2.—A sketch of the physical layout of the pastures.

ESTABLISHMENT OF CLOVER AND GRASSES

One ton of dolomitic limestone, 600 pounds of 16% superphosphate, and 100 pounds of 50% muriate of potash per acre were applied broadcast to the entire area in the fall of 1941. Three pounds of Louisiana-grown white clover seed were broadcast and covered lightly by scarifying the sod with a spring-tooth harrow.[4] Each fall thereafter all of the pastures received 300 pounds of 18% superphosphate and 50 pounds of 60% muriate of potash per acre. The pastures were mowed each year to control weeds.

The native grasses were dominantly carpet grass, *Axonopus compressus*, on the lower lying areas and Bermuda grass, *Cynodon dactylon*, on the slopes. Dallis grass, *Paspalum dilatatum*, came in volunteer on all of the pastures and increased each year as the experiment advanced to give considerable summer grazing. There was

[4]Based on recent studies of methods of preparing native grass sods for white clover, the grass sod should be thoroughly scarified or turned under and disked down. The limestone and fertilizer should be incorporated in the first 2 to 3 inches by disking or harrowing.

considerable common lespedeza, *Lespedeza striata*, and native hop clover, *Trifolium sp.*, on the better drained areas in the bottom land pastures and in the sod on the hillside pasture. Hop clover was the dominant legume in the hillside pasture sod, except in 1934 when a good growth of crimson clover was obtained.

STOCKING THE PASTURES AND RELATED FACTORS

A herd of 25 purebred Aberdeen Angus cows and their calves were grazed on these pastures without supplementary feed during the 7-months pasture season (April to October). The cows were wintered on sorghum cane silage, native grass, and oat hay, and 1 to 2 pounds of cottonseed meal per head daily. On the average the cows would go on pasture in April weighing from 100 to 150 pounds less than they weighed in the fall. In general the practice was followed of stocking each plot for maximum gain *within the restrictions of the particular system followed on that paddock*. This meant that occasionally during periods of limited rainfall it was necessary to transfer some of the cows to a reserve pasture. Also, in late summer as the larger calves were weaned and removed from the herd, it became necessary to bring in extra cows. Most of the cows were bred to drop their calves before going on the test, although some of the cows calved while on the pastures each year. The calves were removed and weaned each summer or fall as they reached 400 to 450 pounds in weight, but the dry cows were continued on the paddock until the herd was removed in October. The animals were turned on the plots about April 1, when the white clover was from 2 to 4 inches high.

The test animals were weighed twice a month throughout the grazing season, at which time the pastures were carefully inspected and the rate of a stocking adjusted to fit the amount of available pasturage *within the restrictions of the different systems of grazing*. Paddock 1, which was continuously and heavily grazed, was generally stocked with about twice the load of the moderately grazed pastures. Special effort was made to stock all pastures heavy enough in September to remove any excess grass. It should be emphasized that in any grazing experiment of this type the judgment of the supervisor in regulating rate of stocking is of major importance. Weighing techniques and animal and soil variation are other sources of experimental error which may be of considerable magnitude. After carefully inspecting the pastures, the agronomists regulated the rate of stocking at each weighing period and personally supervised the weighing in the experiment reported herein. Because of the amount of land, number of animals, and expense involved, no replication was attempted in this experiment. Very few grazing experiments have been conducted in this country that have provided a reliable estimate of experimental error. For these reasons no attempt will be made in an analysis of the results of this test to attach significance to small differences in animal gains.

DISCUSSION OF RESULTS

COMPARATIVE RETURNS FROM DIFFERENT RATES OF STOCKING

The amounts of beef produced per acre per year under the different systems of management are presented in Table 1. Based on the 4 years' results, including observations which were made on the survival of white clover in the sods of the several pastures, a moderate rate of stocking (about 2 acres per brood cow and calf) and continuous grazing from April 1 to about October 15 appeared to be the best system. This pasture (No. 3) produced about as much beef as any of the systems employed and carried some reserve vegetation most of the time.

Continuous heavy grazing (about 1 acre per cow and calf), however, did not kill the white clover where the soil moisture was favorable and the pasture was adequately fertilized. Although the highest beef gains were recorded for this system, the slight difference in yields between heavy and moderate rates of stocking is not considered significant. There are two serious objections to heavy stocking of

pastures. First, there was very little or no reserve pasturage present at any time under this system of grazing. In a farming system this immediately calls for a large reserve permanent pasture or ample supplementary grazing during relatively short periods of insufficient rainfall. The second important objection to severely close grazing of pastures is its effect on the quality of beef produced. No attempt was made in this investigation to study the effect of rate of stocking on quality of beef. Other investigators (1, 12) and livestock producers have observed that heavily stocked pastures produce poor quality beef.

TABLE 1.—*Beef yields as affected by grazing management, main station, Auburn, Ala., 1942–45.*

Pasture No.	Grazing treatment*		Pounds of beef per acre				
	System of management	Actual grazing load, acres per cow†	1942	1943	1944	1945	4-year av.
1	Continuous and heavy grazing	1.21	317	225	281	302	281
2	Pasture divided into 3 lots and grazing rotated, changing every 2 weeks; moderate stocking	2.16	204	153	211	173	185
3	Continuous and moderate stocking with further reduction if necessary to allow white clover seed crop	2.05	336	222	238	271	267
4	Moderate stocking and cows removed May 1 until white clover seed crop matured	1.90	288	184	265	246	246
5	Upland pasture stocked moderately (crimson clover one year and hop clover-Bermuda grass other years)	2.12	165	244	276	275	240

*All pastures fertilized alike as follows: Fall of 1941, 1 ton of limestone, 600 pounds of 16% superphosphate, and 100 pounds of 50% muriate of potash per acre. Each year since 300 pounds of 18% superphosphate and 50 pounds of 60% muriate of potash per acre. All pastures except No. 5 were composed of white clover-grass sods on bottom lands.

†Calves not included in these data. Average of two calves for every three cows for the grazing season.

There was no evidence that removing the stock from white clover pastures during May (No. 4) to allow the clover to mature a heavy seed crop was of any value.

ROTATIONAL GRAZING

The so-called Hohenheim system of pasture management has as one of its features rotational grazing whereby a pasture is grazed and rested alternately throughout the season. The pasture that was subjected to rotational grazing in the Auburn test produced less beef than any of the other bottom land pastures. White clover did not survive as well on the rotated pastures as on those areas continuously grazed. Also native smut grass, *Sporobolus poiretii*, of low palatability appeared to crowd out the better grasses in the alternately grazed pastures.

A search of the literature revealed very little convincing evidence that rotational grazing of white clover-grass pastures in the United States is of sufficient value to pay for the additional expense of fencing and other incidentals. In spite of the paucity of data to show the value of rotational grazing, several pasture specialists in the southeastern states (2,11) have recommended this practice in recent years. Woodward, Shepherd, and Hein (13) in a study of the Hohenheim system with dairy cows on bluegrass-clover pastures near Beltsville, Md., concluded that it was doubtful if the rotational feature would pay for itself on pastures of low to medium productivity. Salter, Gerlaugh, and Welton (10) reported no benefit from rotational grazing of bluegrass in Ohio. Less than 10% increase in total digestible nutrients as a result of rotational grazing was reported in studies with dairy cows on the Western Washington (4) and Virginia Experiment Stations (5).

OVERGRAZING VERSUS UNDERGRAZING

A great deal has been said in recent years about the evils of overgrazing permanent pastures. Observing livestock farmers in the Southeast have seen areas so closely grazed that they become little more than exercise lots for the livestock. The results of this study and observations made in other sections of Alabama, however, indicate that white clover will withstand severe grazing once it becomes established on areas to which it is naturally adapted, *provided it receives the proper amounts and kinds of fertilizer*. This does not mean, however, that maximum beef yields are produced by overgrazing. It is believed important to permit new seedings of white clover to make a good seed crop the first year and also that the clover should be allowed to make several inches of growth in the spring before the cattle are put on these pastures. Under all the systems of grazing tested, a partial stand of white clover survived the summers on those areas having favorable soil moisture conditions. Close grazing of summer grasses in late August or September tends to favor white clover survival.

It appears that, under even the best system of management, it is necessary occasionally to renovate established white clover-grass sods in Central and South Alabama. The grasses (carpet grass principally) after a few years of stimulated growth provide too much competition for the clover during the hot summer months. As a result the clover becomes an annual and it is necessary to destroy the grass sod to revive the clover. Close grazing of the grasses in late summer appears to delay the need for this renovation procedure.

UPLAND VERSUS BOTTOM LAND PASTURES

The hillside pasture, which included primarily hop clover, Bermuda grass, and lespedeza, produced as much beef in 1944 and 1945 as the best of the bottomland pastures. In the fall of 1942, this area was seeded to crimson clover. The clover was grazed during April but was permitted to make a seed crop. Although the crimson clover failed to reseed successfully the next year, the soil-improving effect

of this crop and other legumes stimulated the Bermuda grass to such an extent that beef gains on this pasture were increased 67% over that produced in 1942. The returns from this sandy hillside pasture under reasonable fertilizer treatment point to the possibility of beef production on such areas if the best combination of grasses and legumes are well fertilized and properly managed.

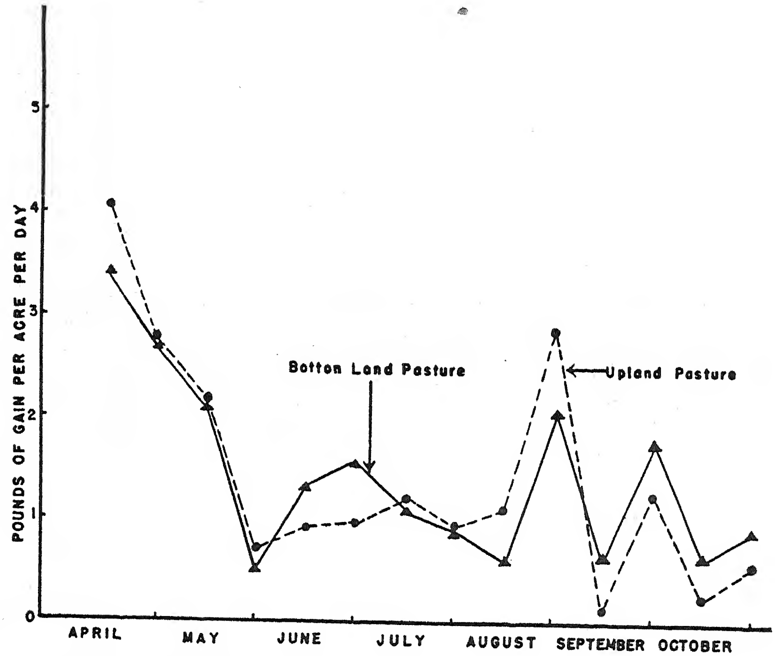

FIG. 3.—Seasonal distribution of beef gains from bottom land and upland pastures, 4-year average.

SEASONAL DISTRIBUTION OF BEEF GAINS AND RAINFALL

The general trends in the distribution of gains made on these pastures over the 7-month period (Fig. 3) are similar to those in the production curves that have been reported for spring clover-grass pastures in the Black Belt region of Alabama (1). The distribution of gains on the upland pasture is compared with gains from the bottom land pastures in Table 2. Rainfall and beef production by 2-week periods are given in Table 3. Under the best system of grazing employed in this study, there were 2-week periods during 3 out of the 4 years when net losses occurred. The calves usually continued to gain or at least to maintain themselves during these periods but the cows lost weight.

Maximum gains were made in April, followed by a definite period of low production the last 2 weeks in May. Gains of beef then picked up in June but reached another low in late July or the first of August. Another peak in gains was reached in late August. No prolonged

drouths occurred during the 4 years of this study and total rainfall by 2-week periods did not appear to be highly correlated with beef gains. The fluctuations in the production curve (Fig. 3) obviously are related to changes in species in the pasture sod. White clover was observed to reach its peak in late April but receded by late May. There is an apparent lag between the clover peak and the growth of summer grasses in June which accounts for the low beef gains during the last 2 weeks of May. Hop clover reaches its peak growth early and disappears rapidly. Summer grasses reach their peak production in late August and early September, which is reflected in a definite peak in beef production (Fig. 3).

TABLE 2.—*Seasonal distribution of beef gains from bottom land pasture compared with upland pasture, main station, Auburn, Ala., 1942–45.*

Year	Average daily gains of beef per acre*													
	April		May		June		July		Aug.		Sept.		Oct.	
	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–15	16–30	1–15	16–31
	Bottom Land Pasture†													
1942	2.75	4.10	2.01	0.48	0.17	3.69	0.51	1.33	−0.45	2.22	1.84	2.67	—	—
1943	2.46	1.81	2.53	−0.45	1.61	0.23	3.37	0.64	0.89	2.37	0.27	—	—	—
1944	3.77	2.79	2.77	0.60	1.45	1.46	0.38	1.81	1.44	—	—	—	—	—
1945	4.46	1.96	1.10	1.43	2.14	0.87	0.16	1.14	0.38	1.58	−0.13	0.85	0.63	0.89
Av.	3.40	2.67	2.10	0.52	1.34	1.56	1.11	0.91	0.57	2.06	0.66	1.76	0.63	0.89
	Upland Pasture‡													
1942	2.70	1.76	0.94	0	−0.04	1.80	0.49	0.33	−0.98	2.87	0.08	1.64	—	—
1943	7.09	3.20	—	—	—	0.82	3.03	−0.90	1.89	3.36	0.16	—	—	—
1944	2.62	4.92	3.77	0.66	1.31	0.74	0.41	1.97	1.15	—	—	—	—	—
1945	3.77	1.07	1.80	1.48	1.48	0.49	0.82	2.30	2.30	2.30	0.16	0.82	0.25	0.57
Av.	4.05	2.74	2.17	0.71	0.92	0.96	1.19	0.93	1.09	2.84	0.13	1.23	0.25	0.57

*For periods where weights are not recorded weighings were not made at 2-week intervals, but at end of grazing season.

†Bottom land pasture vegetation was white clover, Dallis, and carpet grass. Average of all bottom land pastures.

‡Upland pasture composed of hop clover, Bermuda grass, and common lespedeza except for crimson clover in the spring of 1943.

CALF SIZE AND RATE OF GAIN

Calf gains were tabulated separately from the cow gains for the 1945 season and are grouped by size classes in Table 4. During the first 2 weeks on pasture in April, the calves gained in weight in proportion to their size. As an average for the entire grazing season, however, there was no effect of size of calf on rate of gain. The cows serving as a buffer during periods of short pasturage enabled the calves to show a remarkably uniform rate of gain throughout the season regardless of size as compared with the fluctuations in total beef gains. The calves gained on the average about 2 pounds per day. At this rate it would require approximately 5 months to produce 400-pound calves (average weight at birth about 80 pounds).

TABLE 3.—*Beef gains at 2-week intervals compared with rainfall of previous 2 weeks, main station, Auburn, Ala., 1942–45.**

	April		May		June		July		August	
	1–15	16–30	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31
1942										
Rainfall, inches	5.5	2.2	0.0	1.7	2.3	4.9	1.3	1.7	1.8	3.2
Beef gains per acre, lbs.	38	50	19	4	2	46	7	16	−8	33
1943										
Rainfall, inches	5.7	1.5	1.8	1.7	1.1	0.4	2.0	5.8	2.0	3.6
Beef gains per acre, lbs.	48	30	21	−4	18	1	46	−10	16	36
1944										
Rainfall, inches	6.3	0.3	9.0	0.7	4.1	1.8	1.3	2.3	0.9	2.8
Beef gains per acre, lbs.	49	46	34	7	20	18	5	26	6	32
1945										
Rainfall, inches	3.9	1.8	10.6	5.0	0.0	1.6	2.6	1.3	2.4	0.8
Beef gains per acre, lbs.	60	25	15	16	28	11	4	19	4	17
Average, 4 Years										
Rainfall, inches	5.3	1.5	5.4	2.3	1.9	2.2	1.8	2.8	1.8	2.6
Beef gains per acre, lbs.	49	38	22	6	17	19	16	13	5	30

*Data on beef gains are averages of all pastures (upland and bottom land). Rainfall shown for previous 2-week period as a week or 10-day time lag is required for the vegetation to respond.

BEEF PRODUCTION COMPARED WITH RETURNS FROM WHITE CLOVER-GRASS PASTURES IN OTHER SECTIONS

The beef yields from fertilized bottom land pastures at Auburn, Alabama, (274 pounds per acre per year) compared favorably with beef production on lime land pastures of the Black Belt section of the state (1). The 10-year average yield of beef was 307 pounds from white clover-grass plots on the Black Belt Substation, which received a comparable rate of phosphate. The Georgia Coastal Plain Experiment Station reported (12) a 10-year average production of 321 pounds of beef per acre from a fertilized (600 pounds of 6–12–6 annually) grass-clover pasture on Plummer sandy loam at Tifton, Ga. The same investigators reported a 126-pound-per-acre beef yield from a fertilized lespedeza-Bermuda grass pasture on Tifton sandy loam. A fertilized bluegrass-white clover pasture on the Middle Tennessee Experiment Station (9) produced a 5-year average of 205 pounds of beef per acre per year. Bledsoe and Sell (3) in Georgia reported that steers gained from 170 to 263 pounds per acre per year on improved Bermuda grass-white clover pastures. Hutcheson (6) recorded an average gain for 4 years of 156 pounds of beef per acre per year from fertilized white clover-bluegrass pastures on a farm in Piedmont, Va. He pointed out that the proper management of pastures became important when additional expense for fertilizer

and lime is incurred. Blaser, Stokes, Warner, Ritchey, and Killinger (2) reported that beef yields of 200 to 675 pounds per acre per year could be expected from clover-grass mixtures under Florida conditions.

TABLE 4.—*Relation between size of calf and rate of gain, main station, Auburn, Ala., 1945*

Size class	Average gain (pounds per calf per 2 weeks) and number of calves*															
	Apr. 2–16		Apr. 16–30		Apr. 30–May 14		May 14–28		May 28–June 11		June 11–25		June 25–July 9		July 9–23	
	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain
Less than 150 lbs.	5	20	4	38	2	30	1	20	–	—	1	30	2	30	3	30
150–250 lbs.	8	35	9	44	6	22	7	17	7	44	5	30	2	15	1	30
250–350 lbs.	2	45	3	43	7	26	7	21	7	47	4	30	9	18	8	30
Greater than 350 lbs.	–	—	–	—	2	25	2	25	3	43	8	30	8	19	9	27

Size class	July 23–Aug. 6		Aug. 6–30		Aug. 20–Sept. 4		Sept. 4–17		Sept. 17–Oct. 1		Oct. 1–15		Average gain per 2 weeks
	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	No. of calves	Av. gain	
Less than 150 lbs.	1	20	1	30	–	—	–	—	–	—	–	—	31
150–250 lbs.	2	25	2	35	2	15	3	17	3	23	–	—	30
250–350 lbs.	8	23	6	48	1	20	–	—	–	—	3	13	30
Greater than 350 lbs.	5	26	7	26	8	3	8	20	8	25	8	36	24

*Total number of calves was not constant throughout the season since the rate of stocking was adjusted to fit the available pasturage and the calves were weaned as they reached 400 to 450 pounds in weight.

The best pastures in the Auburn test produced a gross return above fertilizer cost of $22.75 per acre per year (beef valued at 10c per pound). The average cost per acre for fertilizer and lime was $4.75 per year.

In view of these reports, it would appear that the 4-year average beef production from these pastures on soils of medium to low inherent fertility would compare favorably with returns from white clover-grass pastures in several of the southeastern states. The po-

tential for beef production on such areas in the Coastal Plains and Piedmont Regions is certainly not being realized under present management of these areas. Much of the land in these sections that is best adapted to the growth of white clover is producing little or no income and represents an undeveloped natural resource of tremendous magnitude.

CONCLUSIONS

Based on a 4-year study of different rates of stocking and methods of grazing white clover-grass pastures, it was concluded that

1. A moderate rate of stocking (about 2 acres per cow and calf) and continuous grazing from April 1 to about October 15 appeared to be the best system.

2. Continuous heavy grazing (about 1 acre per cow and calf), however, did not kill white clover when properly fertilized.

3. There was no evidence that removing the stock during May to allow the clover to mature a heavy seed crop was of any value.

4. Rotational grazing, in which the pasture was divided into subpaddocks and each paddock was grazed heavily for 2 weeks and then rested a month, was not a good system under the conditions of this study.

5. A partial stand of white clover behaved as perennial plants on those areas with favorable moisture supply under all of the systems of grazing tested. Close grazing, particularly in late summer, appeared to favor the survival of white clover as a true perennial.

6. Beef gains from fertilized bottom land pastures at Auburn, Ala. (274 pounds per acre per year) compare favorably with beef production on the lime land pastures of the Black Belt region of the state, and with reported beef yields from similar pastures in several of the southeastern states.

LITERATURE CITED

1. BAKER, K. G., and MAYTON, E. L. A year-around grazing program for the alkaline soils of the Black Belt of Alabama. Jour. Amer. Soc. Agron., 36: 740–748. 1944.
2. BLASER, R. E., STOKES, W. E., WARNER, J. D., RITCHEY, G. E., and KILLINGER, G. B. Pastures for Florida. Fla. Agr. Exp. Sta. Bul. 409. 1945.
3. BLEDSOE, R. P., and SELL, O. E. Permanent pastures. Ga. Agr. Exp. Sta. Bul. 207. 1940
4. HODGSON, R. E., GRUNDER, M. S., KNOTT, J. C., and ELLINGTON, E. V. A comparison of rotational and continuous grazing of pastures in Western Washington. Wash. Agr. Exp. Sta. Bul. 294. 1934.
5. HOLDAWAY, C. W., and PRATT, A. D. Progress report of pasture fertilization at the Virginia Agricultural Experiment Station. Jour. Dairy Sci., 16:95–99. 1933.
6. HUTCHESON, T. B. Experiments and observations on pasture management in Appomattox County. Va. Agr. Exp. Sta. Bul. 333. 1941.
7. LOUNSBURY, C., WILDERMUTH, R., SWENSON, G. A., STRIKER, M. M., BRACKEEN, L. G., SHERARD, H., McIntyre, C. L., and CALLAHAM, V. O. Soil Survey, Macon County, Ala. 1944.
8. MAYTON, E. L., and STURKIE, D. G. Pastures for Alabama. Ala. Agr. Exp. Sta. Leaflet No. 7. 1934.

9. NEEL, L. R. Permanent pastures. SRAC–5, Agr. Adj. Adm., U.S.D.A. 1938.
10. SALTER, R. M., GERLAUGH, P., and WELTON, F. A. Nitrogen top-dressings of bluegrass grazed by beef cattle. Ohio Agr. Exp. Sta. Bul. 446. 1930.
11. South Carolina Pasture Committee. Permanent pastures for South Carolina. S. C. Agr. Ext. Serv. Bul. 99. 1942.
12. STEPHENS, J. L. Pastures for the Coastal Plain of Georgia. Ga. Coastal Plain Exp. Sta. Bul. 27. 1942.
13. WOODWARD, T. E., SHEPHERD, J. B., and HEIN, M. A. The Hohenheim system in the management of permanent pastures for dairy cattle. U.S.D.A. Tech. Bul. 660. 1938.

Some Causes for Variation of Coumarin Content in Sweetclover[1]

J.M. SLATENSEK[2]

CONSIDERABLE effort has been expended by plant breeders in an attempt to produce a variety of sweetclover that is free from or relatively low in coumarin. Not only is coumarin associated with the bitter taste characteristic of sweetclover tissue, but it is also indirectly responsible for the "sweetclover bleeding disease" of cattle. When sweetclover hay spoils, the coumarin of the tissue is involved in the formation of 3, 3′-methylenebis (4-hydroxycoumarin), a strong anti-coagulant principle (7, 8).[3] The toxicity is manifested in animals feeding on the spoiled hay by a diminution in the clotting power of the blood and the occurrence of hemorrhages.

The intelligent pursuance of the chemical assay program for isolating plants low in coumarin to be used for further breeding requires a thorough knowledge of coumarin and its behavior in the plant. Specifically, it is essential that the plant breeder be able to distinguish inherent differences in coumarin content from those produced by various environmental factors which have been found to influence the amount of this constituent. The purpose of this paper is to report on studies which have been conducted since 1943 on causes for fluctuation of coumarin content in sweetclover.

REVIEW OF LITERATURE

Several investigators have recognized the need for information regarding the nonheritable causes of variability in coumarin content.

Ufer (10), using a modification of the Obermayer test for coumarin, reported that biennial sweetclover plants tend to be low in coumarin in the early growth stages of the first year, high in the fall of the first year, and low in the early and high in the late stages of the second-year growth.

Investigations by Gelčinskaja and Bordunova (2) showed that coumarin content varies with plant development, reaching a maximum during flowering and then falling off.

Stevenson and Clayton (9) studied the seasonal variation in coumarin content during the two years of plant growth. They found the coumarin of the young seedling to be low and to increase rapidly, reaching a maximum about 46 days after the four-leaf stage. It then fell rather rapidly to the end of the first growing season. In the second year the general trend was a rise in coumarin content to a maximum during the flowering stage, followed by a steady decrease to maturity. These investigators further showed that the coumarin content of the leaves was approximately three times that of the stems.

Based on tests with plants in different stages of second year growth, White and Horner (11) reported that the coumarin content was highest in the very early

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[3]Figures in parenthesis refer to "Literature Cited", p. 604.

stages and lowest at maturity. There was a slight decrease after the early stage followed by another peak at budding, with a steady decrease thereafter to the time of seed setting. In a later year they again tested second year plants at intervals throughout the growing season. In this test the maximum amount of coumarin appeared at the budding stage and it again receded with the setting of seed. In a study of variations in the coumarin content of different parts of the sweetclover plant, these investigators showed it to be higher in newly formed leaves than in old leaves, and that flower buds had an extremely high content.

Horner and White (4) examined the correlation between the coumarin content of the first and second year's growth of a group of plants classified as low and high and found a highly significant correlation of +.87. In a population of only low testing plants, White and Horner (11) failed to obtain a significant correlation of one year's test with the next. Rinke (5) obtained a highly significant correlation value of +.24 between the first and second year coumarin content of 422 plants.

Brink (1) has made a comprehensive study of the distribution and metabolic aspects of coumarin in sweetclover. Certain phases of his work will be referred to later in this paper.

EXPERIMENTAL

Methods of coumarin analysis.—All analyses herein reported are on a dry weight basis, made by means of the fluorometric method of coumarin determination, and results checked by means of the colorimetric method. In the literature review the analyses by other workers were by means of the colorimetric test, unless otherwise stated.

Slatensek and Washburn (6) described a quantitative fluorometric method for the determination of coumarin based on a qualitative test reported by Ufer (10). Subsequent work with the new method has suggested several improvements which have been incorporated in the procedure which follows. This improved method was used for making the fluorometric determinations reported.

Fluorometric procedure.—Ten or more leaves removed from the same relative position on each plant are placed in paper holders (used envelopes serve well) and placed in a drying oven within about an hour after collection. The green leaf material is dried at a temperature of about 95°C for 1½ hours in which time the material becomes crisp and can easily be pulverized and mixed. This drying treatment inactivates tissue enzymes and prevents certain changes which have been found to produce errors with the fluorometric procedure as a result of very slow drying. A 100-mg sample of the pulverized plant material is placed in a dry ¾×6 inch test tube marked for 15 ml. Then 2.5 N NaOH is added to the 15 ml mark. The tubes are loosely stoppered by covering with shell vials and placed in an Arnold steamer maintained at a temperature of 97° C. After heating for 2¼ hours the tubes are removed from the steamer and allowed to stand until cool. The samples, including a blank and a standard of known coumarin content, are then diluted by pipetting 1 ml of the supernatant solution into a 100-ml volumetric flask. After diluting with water to the 100-ml mark, at least 10 ml are poured into a clean ¾×6 inch test tube. At this point the diluted samples are exposed to direct sunlight for 10 minutes. This treatment permits the samples to reach maximum fluorescence quickly in the fluorometer and avoids a sluggish response by this instrument. The tubes are then inserted into the cuvette well of the Coleman photofluorometer No. 12, equipped with B–1 and PC–1 filters, and the readings taken.

The standard can be prepared conveniently by adding 5 ml of a stock coumarin solution (25 mg synthetic coumarin in 50 ml of 2.5 N NaOH and heated for 2¼ hours at 97°C) to a tube containing 97.5 mg of dried alfalfa leaves in 10 ml of 2.5 N NaOH which had also been heated along with the unknown samples. The standard is thoroughly mixed by inverting the tube several times. After diluting 1–100 with water this standard represents 2.5% coumarin.

In making the readings with the Coleman photofluorometer the galvanometer needle is set at 100 for the 2.5% standard and at 0 for the blank (pure alfalfa) and the corresponding readings for the unknown samples are made. The galvanometer values for the unknown samples are then converted to coumarin percentages by reference to a curve previously constructed by plotting the fluorometer values obtained from a series of samples of pure coumarin and alfalfa ranging from 0.1% to 2.5%.

RESULTS

DISTRIBUTION OF COUMARIN IN VARIOUS PARTS OF THE SWEETCLOVER PLANT

Since a relatively small portion of the plant is used as a sample in the analytical procedure, it obviously is of importance to know the distribution of coumarin within the plant. Table 1 shows the percentage in the upper and lower leaves and stems, buds, blossoms, seeds, and roots. These data are the averages for five spaced *Melilotus alba* and five spaced *M. officinalis* plants sampled at the early bud stage, and for a related group of ten plants at the early seed stage. The results reported here are in general agreement with those obtained by Brink (1) and other workers (9, 11) who have conducted studies on the distribution of coumarin in the various parts of the plant.

TABLE 1.—*Coumarin content of various parts of the sweetclover plant at the early bud and the early seed stages of growth, 1944.*

Part of plant	Percentage coumarin, air-dry weight basis
Early Bud Stage	
1. Upper leaves (young)	1.88
2. Lower leaves (old)	0.62
3. Main stems (upper part)	1.65
4. Main stems (lower part)	0.36
5. Buds (racemes ⅓ inch long)	1.72
Early Seed Stage	
6. Upper leaves	1.16
7. Lower leaves	0.44
8. Main stems (upper part)	0.83
9. Main stems (lower part)	0.41
10. Buds (racemes ½–1 inch long)	1.91
11. Blossoms (freshly opened)	1.83
12. Seeds (mostly green)	1.87
13. Roots	1.34

These data and corroborative evidence obtained at various times over a period of several years suggest that coumarin is greatest in tissues of high metabolic activity such as young leaves and buds. The wide variation in coumarin content, especially between the upper and lower leaves of the plant, emphasizes the importance of exercising care in the collection of the sample for chemical analysis. It seems desirable to use the fully expanded leaves from the upper portion of the plant and they should be taken from the same relative position on the different plants. Taking upper leaves in one instance and including lower leaves in another might introduce serious sampling errors.

SEASONAL VARIATION IN COUMARIN CONTENT

This investigation was made to determine the effect of season and stage of plant development upon the coumarin content. At two-

week intervals throughout the two years of plant growth (1943–44) a bulk collection of leaves was made from two solid plantings of *M. alba* (Grundy County) and two of *M. officinalis* (Common Yellow). The two types were within a week of each other in time of maturity. In sampling at each period an effort was made to obtain top leaves from the same relative position on the plants. These samples were analyzed and a graph constructed to show fortnightly variation. Since the two groups varied rather similarly from one period to the next, the four readings at each period were combined for presentation as a single curve in Fig. 1 This curve shows an increase in coumarin content during the first year until a peak of approximately 1.6% is reached at the end of July. After that there is a rather rapid decline until late fall when only about 0.2% coumarin remains in the upper leaves. During the second year there is an increase from early in the season until the maximum is reached at the early flower stage. From then on the coumarin content decreases rapidly as seed-setting progresses.

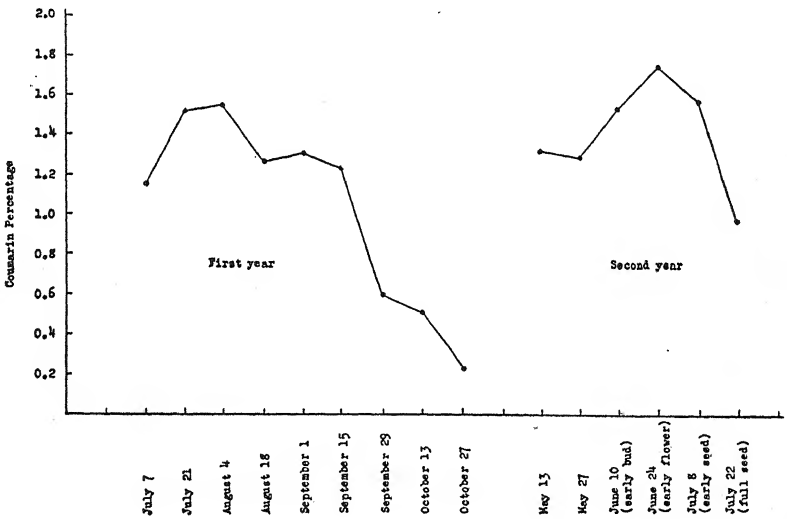

FIG. 1.—Seasonal variation in the coumarin content of sweetclover plants throughout their two years of growth, 1943 and 1944.

Fig. 2 presents the seasonal variation of coumarin in the Evergreen (*M. alba*) variety which was also analyzed at two-week intervals throughout its two years of growth (1944–45). The general trends shown in Fig. 1 were again obtained, but divergences existed on the different dates of sampling, due perhaps to varying climatic conditions and varietal differences in stage of maturity on comparable dates.

It was of interest to learn the fate of the coumarin which disappeared almost completely from the leaves at the end of the first growing season. Some information on this point was gathered by

analyzing the roots as well as the leaves at intervals as the fall progressed. From solid plantings of *M. alba* (Sangamon in 1944, Evergreen in 1945), 15 to 20 plants were selected at random and removed from the soil. The leaves were stripped from the plants, bulked, dried, and ground. The roots from these same plants were cut to a uniform length of 8 inches, bulked, dried, and ground in a Wiley mill. This procedure was repeated at intervals from September 12 to November 20 in 1944 and from September 24 to October 29 in 1945. Roots and leaves from the different periods of sampling were analyzed for both coumarin and crude protein, with the results shown in Table 2.

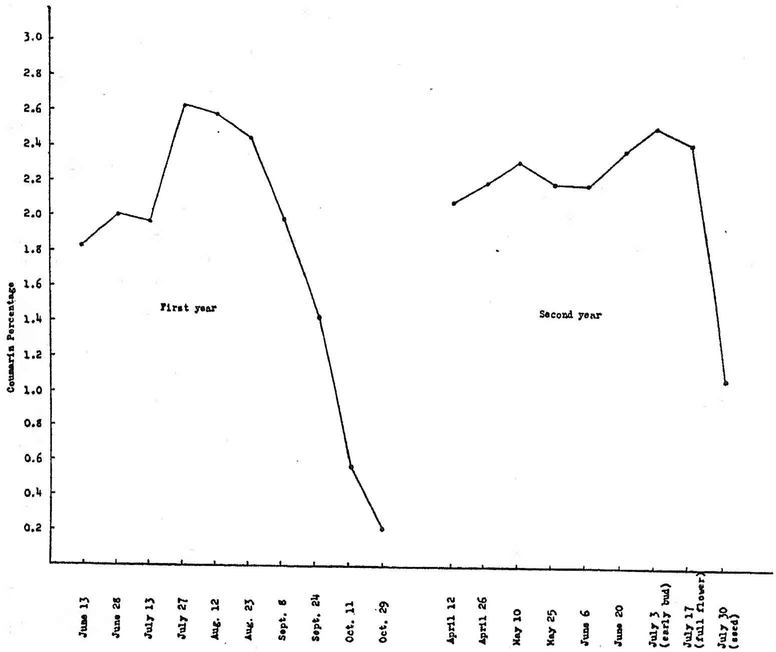

FIG. 2.—Fortnightly variation in the coumarin content of Evergreen sweetclover throughout the two years of growth, 1944 and 1945.

The storage of reserve food substances in the roots of herbaceous, over-wintering plants during the fall months has long been recognized. Graber, *et al.* (3), for example, made a thorough study of organic food reserves, particularly with alfalfa. In connection with their investigations concerning the chemical variation of tops and roots at different stages of growth they showed that the percentage of nitrogen increased greatly in the roots of alfalfa from September 13 to December 12, while there was a corresponding decrease in the tops. The data of Table 2 suggest a similar behavior for coumarin. The translocation of coumarin from the tops to the roots as winter approaches parallels the reduction of protein in the leaves and its increase in the roots during the same period.

TABLE 2.—*Coumarin and crude protein content of top leaves and roots of Sangamon and Evergreen sweetclover plants in the fall of the first year of growth, 1944 and 1945.*

Date	Top leaves		Roots	
	Protein N×6.25, %	Coumarin, %	Protein N×6.25, %	Coumarin, %
	Sangamon, 1944			
Sept. 12	31.1	0.96	16.1	0.79
Sept. 21	30.1	0.82	16.7	0.82
Oct. 9	25.4	0.62	19.5	0.93
Nov. 20*	24.6	0.18	22.3	0.98
	Evergreen, 1945			
Sept. 24	26.7	1.46	15.5	0.42
Oct. 11	20.8	0.58	16.1	0.45
Oct. 29†	15.9	0.22	19.7	0.54

*First killing frost Nov. 4, 1944.
†First killing frost Oct. 9, 1945.

EFFECT OF LIGHT INTENSITY AND SOIL FERTILIZATION WITH NITROGEN ON COUMARIN CONTENT

This experiment was designed to determine the effect of light intensity and soil fertility on the coumarin content of greenhouse plants. For this purpose four plants were grown from stem cuttings taken from each of eight different sweetclover plants growing in the greenhouse. Each of the four plants in the eight clones was given a different one of the following four treatments:

1. Plant grown in light without fertilizer
2. Plant grown in light with fertilizer
3. Plant grown in shade without fertilizer
4. Plant grown in shade with fertilizer

All cuttings were grown in ½-gallon glazed, earthenware jars containing a mixture of 14 parts silty-clay loam soil and three parts sand. The cuttings to be grown with fertilizer were supplied with ammonium nitrate at the rate of 400 pounds per acre. The cuttings to be grown in shade were covered with large-mesh muslin cloth. The plants were randomized and rotated at intervals when watered. The moisture content of the soil in each jar was maintained at approximately 85% of the field carrying capacity. At the end of six weeks, the top growth in each jar was cut off at the soil line and the air-dry weight obtained. All leaves of each plant were stripped, ground and mixed, and then analyzed for coumarin content. The results are presented in Table 3.

On the basis of these results the addition of nitrogen to the soil had no effect on the coumarin content of the plants. With respect to the effect of light it appears that plants grown in shade tend to have a slightly higher percentage of coumarin. This is in agreement with a preliminary trial conducted the previous year (winter greenhouse

1943–44) in which ten clones of two plants each were used. One plant of each clone was grown in shade underneath the greenhouse bench, while the corresponding plant was grown in full light on top of the bench. After 2½ months the plants grown in full light averaged 0.70% coumarin compared to 0.77% for those grown in shade.

TABLE 3.—*Effect of light intensity and soil fertilization with nitrogen upon the air-dry weight and coumarin content of greenhouse sweetclover plants, January 8 to February 24, 1945.*

Clone number	Light*				Shade			
	Nitrogen†		No nitrogen		Nitrogen		No nitrogen	
	Weight, grams	Coumarin, %	Weight, grams	Coumarin, %	Weight, grams	Coumarin, %	Weight, grams	Coumarin, %
1. Sangamon-1	550	0.69	1,030	0.79	415	0.77	360	0.77
2. Sangamon-2	1,380	1.56	1,565	1.36	1,170	1.61	820	1.42
3. Spanish-1	440	1.16	750	1.36	370	1.51	305	1.76
4. Madrid-1	2,300	1.16	960	0.96	630	1.30	680	0.92
5. Sangamon-7	530	1.09	695	1.19	300	1.19	420	0.92
6. Madrid-2	1,170	0.74	950	0.87	650	0.93	490	1.06
7. Spanish-2	800	1.09	860	0.94	660	1.26	615	1.22
8. Sangamon-6	1,410	0.49	1,250	0.56	710	0.54	840	0.58
Average	1,072	1.00	1,007	1.00	613	1.14	566	1.08

*Differences in coumarin content between plants grown in light or shade are significant at the 5% point.

†Differences in coumarin content between fertilized and unfertilized plants are not significant statistically.

Although the increases in coumarin content resulting from growth in shade were small, they nevertheless appear to be at variance with results obtained by Brink (1). In growing plants in shade for ten days he found an initial increase followed by a decrease in coumarin content of the leaves to a point below that at the beginning of growth in shade.

CORRELATION BETWEEN COUMARIN CONTENTS OF FIRST AND SECOND YEAR'S GROWTH

This study involved 71 *M. alba* and 20 *M. officinalis* plants which were analyzed on September 15 of their first year of growth (1943) and again on June 5 of their second year. A correlation coefficient was calculated and a highly significant "r" value of +.77 obtained. The data suggest that sweetclover plants tend to maintain the same relative position with respect to coumarin content throughout their two years of growth. Plants selected as low in coumarin during their first year are likely to be relatively low during their second year.

CORRELATION BETWEEN COUMARIN CONTENT OF PARENT PLANT AND PROGENY

The object of this study was to ascertain the extent to which the coumarin character is passed from parent plant to progeny. Twenty-two *M. alba* and nine *M. officinalis* inbred plants of the S_2 generation growing in the 1943 first-year nursery, were selected and analyzed for coumarin on September 23. During the same fall stem cuttings were made from these plants and selfed seed obtained from the cuttings in the greenhouse. Sufficient seed was obtained to grow 12 to 20 plants from each parent plant during the following year. The progeny plants were analyzed for coumarin on August 21, 1944, and a correlation coefficient of +.49 was obtained between the coumarin contents of the parent plant and the average of its progeny. This correlation value is statistically significant at the 5% point. Considering the possibility that the parental material may not have been homozygous for coumarin character and the fact that the coumarin contents lay within a relatively narrow range, a more highly significant correlation was not to be expected. The correlation obtained indicates that variations in coumarin content have a genetic basis, though environmental effects and other causes may obscure the correlation between the parent plants and their progeny, especially when the former do not differ widely in this constituent.

RELATION OF COUMARIN CONTENT TO PLANT VIGOR

In conducting an extensive program of breeding for a low- or coumarin-free variety, it is of importance to know the relation between plant vigor and coumarin content. In other words, is coumarin involved in the vital processes of the sweetclover plant and therefore necessary for its well-being, or can it be eliminated through breeding and selection without affecting the vigor of this legume? To obtain information on this question a correlation study was made between the first year forage yields and the coumarin percentages of 139 spaced, inbred *M. alba* plants growing in the 1943–44 nursery. First year yields were obtained by making two clippings and were expressed as total green weight per plant. At the time of the second clipping (September, 1943) samples were taken for coumarin analysis. The correlation coefficient between first year yield and coumarin content was found to be −.25, a figure which is significant at the 1% point.

In order to interpret correctly this low, yet significant negative correlation between plant vigor and coumarin content it should be borne in mind that the range of coumarin content involved in this study is considered normal for plants analysed in late September. No extremely low coumarin plants were included, since such material was not available. The data obtained merely support the conclusion that for the range of coumarin content encountered in this study (0.20 to 1.20%) high coumarin content is not related to increased vigor.

SUMMARY

Studies were conducted to ascertain some of the causes of coumarin variation as such information might be of assistance in the assay of

plants used in the breeding program for the production of a nonbitter, nontoxic sweetclover. Large differences in coumarin content were shown to exist in different parts of the sweetclover plant, cognizance of which is necessary for development of a proper sampling technique.

In a study of the seasonal variation in coumarin content of biennial sweetclover it was found that the percentage increases during the first year until a peak is reached around the end of July. This is followed by a rather rapid decline until late fall when very little coumarin remains in the leaves. During the second year coumarin increases from early in the season until a maximum is reached at the early flowering stage. Thereafter it decreases rapidly until maturity. A seasonal variability curve was constructed which can be used for roughly adjusting to a common date all coumarin values obtained by analyses at different times of the year.

With the rapid decline of coumarin in the tops in the fall of the first year there occurred an increase of coumarin in the roots of the plant. Protein content varied similarly in this respect.

Investigations on the effect of light and nitrogen fertilization showed that plants grown in shade tended to have a slightly higher coumarin content than comparable plants grown in full light. Nitrogen fertilization, at the rate applied in this experiment, was found to have no significant effect on coumarin content.

Statistically significant, positive correlations were found to exist between (a) coumarin contents of the first and the second year's growth, and (b) coumarin contents of inbred parent plants and those of their progenies. A negative correlation of low magnitude was found between plant vigor and coumarin content.

Certain improvements have been made in the fluorometric method of coumarin determination and the revised procedure is presented.

LITERATURE CITED

1. Brink, V. C. The content, distribution, and some metabolic aspects of coumarin in sweetclover, *Melilotus alba* Des. Summaries of Doctoral Dissertations, Univ. Wisconsin, 6:41–42. 1942.
2. Gelčinskaja, R. B., and Bordunova M. A. Breeding coumarin-free sweetclover. Trudy prikl. Bot. Genet. i Selekcii., 3:315–323. 1934. (Herbage Abstracts, 6:116. 1936.)
3. Graber, L. F., Nelson, N. T., Leukel, W. A., and Albert, W. B. Organic food reserves in relation to the growth of alfalfa and other perennial herbaceous plants. Wis. Agr. Exp. Sta. Res. Bul. 80. 1927.
4. Horner, W. H., and White, W. J. Investigations concerning the coumarin content of sweetclover. III. The inheritance of the low coumarin character. Sci. Agr., 22:85–92. 1941.
5. Rinke, E. H. Inheritance of coumarin in sweetclover. Jour. Amer. Soc. Agron, 37:635–642. 1945.
6. Slatensek, J. M., and Washburn, E. Roger. A rapid, fluorometric method for the determination of coumarin and related compounds in sweetclover. Jour. Amer. Soc. Agron., 36:704–708. 1944.
7. Smith, W. K., and Brink, R. A. Relation of bitterness to the toxic principle in sweetclover. Jour. Agr. Res., 57:145–154. 1938.
8. Stahmann, M. A., Huebner, C. F., and Link, K. P. Studies on the hemorrhagic sweetclover disease: V Identification and synthesis of the hemorrhagic agent. Jour. Biol. Chem., 138:513–527. 1941.

9. STEVENSON, T. M., and CLAYTON, J. S. Investigations relative to the breeding of coumarin-free sweetclover, *Melilotus*. Can. Jour. Res., 14C:153–165. 1936.

10. UFER, M. Wege und Ergebnisse der züchterischen Arbeit am Steinklee. Der Züchter, 6:255–258. 1934.

11. WHITE, W. J., and HORNER, W. H. Investigations concerning the coumarin content of sweetclover. II. Sources of variations in tests for coumarin content. Sci. Agr., 21:29–35. 1940.

Linkage Relationships of a Gene in Corn Determining Susceptibility to a Helminthosporium Leaf Spot[1]

ARNOLD J. ULLSTRUP AND ARTHUR M. BRUNSON[2]

ONE of the helminthosporium leaf spots of corn, *Zea mays* L., was originally described as being caused by *Helminthosporium maydis* Niskado and Miyake (2)[3], and inheritance of susceptibility to the disease was reported under this binomial (3). Subsequent studies have shown the pathogen to be distinct from *H. maydis*, and the binomial, *H. carbonum* Ull. was assigned to the causal fungus (4). Since susceptibility was shown to be inherited as a mongenic recessive and the symbol *Hm hm* assigned to the genic pair, studies have been in progress to determine their linkage relationships. This paper reports the results of these investigations.

METHODS AND MATERIALS

Appropriate crosses were made between a series of translocation stocks in which sugary endosperm was used as a marker for the chromosomal interchange, and two inbred lines of yellow dent corn, Pr and K61, homozygous for susceptibility to the disease[4]. The F_1 plants of these several crosses were backcrossed with pollen from double recessives (sugary, susceptible). The kernels of backcross progenies were divided into sugary and starchy groups and planted in the greenhouse.

When the seedlings attained the 3 to 4 leaf stage they were inoculated by atomizing a spore suspension of *H. carbonum*, race 1, over the leaves. One week later seedlings grown from starchy and sugary kernels were classified for disease reaction. Symptoms were clear cut, showing either distinct well-developed lesions in case of susceptible segregates, or small yellowish flecks characteristic of the resistant plants.

Since preliminary results had indicated that the gene, *hm*, controlling susceptibility probably was located in the first chromosome, crosses also were made between the homozygous susceptible, red cob, inbred line Pr, and a linkage tester stock that was white cob, resistant, brachytic, and fine stripe-1. Multiple recessives—white cob, susceptible, brachytic, and fine stripe—in the F_2 generation were selfed and crossed subsequently with red cob, resistant, normal stocks. The F_1 plants of the latter cross were backcrossed with multiple recessives and the resulting progenies were planted in the field and inoculated with a spore suspension of the pathogen. The disease reaction, plant character, and cob color were recorded for each plant at appropriate intervals after inoculation.

RESULTS AND CONCLUSIONS

The use of translocation stocks in which sugary endosperm was employed as a marker for the interchange and the fact that the dis-

[1]Contribution from the Division of Cereals Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Botany and Plant Pathology, Purdue University Agricultural Experiment Station, Lafayette, Ind. Journal Paper No. 289 of the Purdue University Agricultural Experiment Station. Received for publication March 12, 1947.

[2]Pathologist and Senior Agronomist, respectively, Division of Cereal Crops and Diseases.

[3]Figures in parenthesis refer to "Literature Cited", p. 609.

[4]The authors are particularly grateful to E. G. Anderson, California Institute of Technology, who supplied the translocation stocks and made the F_1 crosses with these stocks and the susceptible inbred lines.

ease reaction could be determined in the seedling stage provided means for testing rather large populations with a minimum of effort. The results presented in Table 1 show a highly significant division from an expected 1:1:1:1 backcross ratio in the progenies involving interchanges between chromosomes 1 and 4. In the progenies involving all other interchanges the deviations from the ratio expected in independent inheritance are nonsignificant. These results strongly suggest that the gene, *hm*, determining the inheritance of susceptibility to infection by *H. carbonum*, race 1, is located on chromosome 1.

TABLE 1.—*Segregation of seedlings in backcross progenies in which su endosperm was used as a marker for chromosomal interchanges.*

F_1 cross	Number of kernels planted*		Sugary		Starchy		Chi square values	Range of "P"
	Sugary	Starchy	Resistant	Susceptible	Resistant	Susceptible		
suT1-4a×Pr.	1,344	1,149	921	317	190	912	767.0	<.01
K61×suT1-4a. . . .	924	894	664	176	150	703	642.0	<.01
suT2-4a×Pr.	408	475	173	207	234	341	3.1	.2-.3
K61×suT2-4a. . . .	514	675	223	259	319	344	3.6	.1-.2
suT2-4c×Pr.	566	512	266	239	245	238	1.5	.3-.5
K61×suT2-4c. . . .	516	511	240	237	248	237	0.3	.5-.9
suTuT4-5b×Pr . .	458	476	199	206	230	230	0.1	.5-.9
K61×suTuT4-5b.	250	273	120	114	133	139	0.3	.5-.9
Pr×suT4-6a.	478	495	190	205	240	221	1.3	.5-.9
K61×suT4-6a. . . .	443	484	187	181	255	218	3.0	.2-.3
Pr×suT4-8.	336	437	157	161	224	188	0.2	.5-.9
Pr×suT4-9a.	548	545	227	219	244	249	0.8	.5-.9
K61×suT4-9a. . . .	252	251	114	109	115	128	3.2	.2-.3
K61×suT4-10b . .	257	245	127	125	112	119	0.2	.5-.9

*Also represented kernel ratios as observed on ears.

From the relative frequency of double crossovers it was determined that the order of the genes was P-hm-br-f_1. No triple crossovers were found. The results presented in Table 2 indicate that the gene, *hm*, lies 32.8 units to the right of the *P* locus and 14.3 units to the left of the *br* locus.

These data conform closely to those reported in the literature (1) for the distance between *P* and *br*. A map of the left end of the first chromosome as determined from these results is as follows:

P	hm	br	f_1
32.8	14.3	4.0	

A total of 46 plants of the genotype *hm hm br br* $f_1 f_1$ were barren as a result of smut infection or other unknown causes so that cob color could not be determined. Some of these may account for the lower

number of susceptible segregates recorded in Table 2. Seventeen other plants distributed over five other genotypes also were barren.

TABLE 2.—*Backcross ratios in a four-point test in which the F_1 genotype was* $\frac{P\ HM\ Br\ F_1}{p\ hm\ br\ f_1}$.

Progeny No.	Total plants	Parental combinations	Recombinations					
			Region 1	Region 2	Region 3	Regions 1 and 2	Regions 1 and 3	Regions 2 and 3
1	142	39 32 71	23 20 43 30.3%	6 2 8 5.6%	3 3 6 4.2%	4 7 11 7.7%	2 1 3 2.1%	0 0 0 0.0%
2	152	37 31 68	26 25 51 33.3%	16 8 24 15.7%	1 3 4 3.3%	2 3 5 3.3%	0 0 0 0.0%	0 0 0 0.0%
3	142	31 35 66	25 26 51 35.9%	4 7 11 7.7%	2 4 6 4.2%	3 3 6 4.2%	0 2 2 1.4%	0 0 0 0.0%
4	143	34 23 57	27 32 59 41.3%	10 5 15 10.5%	2 2 4 2.8%	2 4 6 4.2%	0 2 2 1.4%	0 0 0 0.0%
5	153	36 39 75	24 24 48 31.4%	11 10 21 13.7%	1 0 1 0.7%	4 2 6 3.9%	1 1 2 1.3%	0 0 0 0.0%
6	160	43 36 79	27 26 53 33.1%	6 4 10 6.2%	2 3 5 3.1%	7 3 10 6.2%	1 2 3 1.9%	0 0 0 0.0%
7	154	40 39 79	25 28 53 34.4%	6 9 15 9.7%	0 1 1 0.6%	2 3 5 3.2%	0 1 1 0.6%	0 0 0 0.0%
8	143	43 31 74	21 27 48 33.6%	6 9 15 10.5%	0 3 3 2.1%	1 1 2 1.4%	1 0 1 0.7%	0 0 0 0.0%
9	149	44 34 78	21 20 41 27.5%	10 9 19 12.7%	1 2 3 2.0%	4 2 6 4.0%	0 0 0 0.0%	1 1 2 1.3%
10	141	47 28 75	30 13 43 30.3%	3 8 11 7.7%	4 1 5 3.5%	2 1 3 2.1%	3 1 4 2.8%	0 0 0 0.0%
11	152	42 36 78	22 23 45 29.6 %	7 8 15 9.9%	2 1 3 2.0%	4 2 6 3.9%	2 0 2 1.3%	0 3 3 2.0%
Totals	1,631	436 364 800	271 264 535 32.8%	85 79 164 10.0%	18 23 41 2.5%	35 31 66 4.0%	10 10 20 1.2%	1 4 5 0.3%

Recombination percentage: *P hm* 38.0, *hm br* 14.3, *br f_1* 4.0.

In this test the severity of disease reaction was appreciably less than is found on susceptible inbred lines. This condition was observed to be constant in all progenies throughout the entire population. The intensity, however, was of a sufficiently high degree to differentiate easily between resistant and susceptible segregates. In one respect this situation was an advantage in that the disease did not prevent ear formation or rot the ears, as had been observed in inbred lines when severely infected, so that cob color was obscured. The reason for the low level of severity of disease in unknown. Since the condition was characterized by a smaller size of lesion rather than by a lesser number, neither abundance of inoculum nor environmental conditions, which were very favorable, can account for the failure of full expression of the disease. A susceptible inbred line close to the test plot was severely parasitized by secondary inoculum arising from the test plot.

LITERATURE CITED

1. EMERSON, R. A., BEADLE, G. W., and FRASER, A. C. Summary of linkage studies in maize. Cornell Univ. Agr. Exp. Sta. Mem. 180: 1–83. 1935.
2. ULLSTRUP, A. J. Two physiologic races of *Helminthosporium maydis* in the Corn Belt. Phytopath., 31: 508–521. 1941.
3. ————.Inheritance of susceptibility to infection by *Helminthosporium maydis* Race I in Maize. Jour. Agr. Res., 63: 331–334. 1941.
4. ————. Further studies on a species of Helminthosporium parasitizing corn. Phytopath., 34: 214–222. 1944.

A Method for the Determination of Soluble Copper in Soils[1]

ALLAN V. KING[2]

DURING the summer of 1946, it became apparent that some potato plants in a field that had been in continuous potato cultivation for a period of about 12 years were developing some sort of malnutrition.

In determining the nutrient ions present in the soil by means of Morgan's (2)[3] quick tests, it was considered important to find out what proportion of the copper applied as bordeaux spray had remained in a relatively soluble state. Judging from the grower's statements, about 500 pounds of elemental copper per acre had been applied during the previous 12 years.

The test evolved was designed to indicate, without elaborate procedure, the relative amounts of soluble copper remaining in the soil.

THE SOIL EXTRACTION

The copper was extracted by Morgan's universal soil extracting solution. This extractant is a weakly ionized organic acid buffered with its sodium salt and was selected for the following reasons:

1. Its buffered H-ion concentration (pH 4.8) is about that of aqueous solutions saturated with carbon dioxide that exist in soil air in humid regions.

2. The total acidity or buffer capacity is such that there is little change in the H-ion concentration even on prolonged contact with normal soils.

3. There are no ions present in the extracting solution that interfere with the copper test.

4. Discoloration of the extract by normal soils is not of sufficient intensity to interfere with the determination.

5. Inasmuch as the intensity of color in the copper test is altered by a change in acidity, a well-buffered solution is necessary to provide a constant H-ion concentration.

6. Maximum amounts of copper are removed from a soil within 5 minutes.

7. The extracting solution is not contaminated by microbial growth.

8. The results of using this extractant are in good accord with crop growth over a wide range of soils.

THE CHEMICAL TEST

The test is based on the fact that when a solution containing both copper and zinc ions reacts with ammonium mercury thiocyanate,

[1]Contribution from the Department of Agronomy, University of Connecticut Extension Service, Storrs, Conn.

[2]Instructor in Agronomy. Received for publication March 14, 1947.

[3]Figures in parenthesis refer to "Literature Cited", p. 614.

$(NH_4)_2[Hg(CNS)_4]$, instead of a mixture of the zinc and copper compounds of an intermediate greenish color being precipitated, a deep violet-colored complex is formed which is probably a complex zinc-copper-mercury thiocyanate. The zinc-mercury complex alone is white; however, when copper is present, even in very minute amounts, the violet color is pronounced and can be used as a sensitive test for copper, as shown by Feigl (1).

This particular qualitative test for copper was selected because:

1. It has a reasonable degree of sensitivity, 0.1γ. (Feigl lists 11 tests ranging in sensitivity from 0.003γ to 1.3γ of copper.)

2. The violet color produced is very stable.

3. The linear relationship of intensity of violet color to concentration of copper, as examined visually, is quite wide (from 5 to 80 p.p.m.).

4. Of the three elements that affect the specificity of this test for copper, two cobalt and nickel, are normally present in negligible amounts. The interference of the third element, ferric ion, is obviated by carrying out the test in the presence of an alkali fluoride.

REAGENTS

A. Morgan's universal solution: Dissolve 100 grams of sodium acetate $(NaC_2H_3O_2 \cdot 3H_2O)$ in 500 ml of distilled water. When dissolved, add 30 ml glacial acetic acid and make up to 1 liter with distilled water.

B. Ammonium mercury thiocyanate: Dissolve 8 grams of mercuric chloride $(HgCl_2)$ and 9 grams of ammonium thiocyanate (NH_4CNS) in 100 ml of distilled water.

C. One per cent solution of zinc acetate.

D. Standard copper solution containing 0.1% Cu^{++} or 1,000 p.p.m.: Weigh out 3.9281 grams of cupric sulfate $(CuSO_4 \cdot 5H_2O)$ and dissolve in 200 ml distilled water. When dissolved, make up to 1 liter with distilled water.

By means of a calibrated pipette, prepare standards as follows:

Solution A ml	Solution D ml	Contains Cu^{++} p.p.m.
20.00	0.00	0
19.90	0.10	5
19.80	0.20	10
19.60	0.40	20
19.40	0.60	30
19.20	0.80	40
19.00	1.00	50
18.80	1.20	60
18.60	1.40	70
18.40	1.60	80

These may be made up and stored in stoppered vials for future use. All chemicals must be of C.P. grade or better.

PROCEDURE

Weigh out 10 grams of recently air-dried 20-mesh soil and add 10 ml of solution A. Allow to stand for 5 minutes with frequent stirring. Filter. To the clear filtrate, add about 0.2 or 0.3 ml of powdered sodium fluoride. Stir or pump several times with a dropping pipette.

Measure out carefully, by means of a calibrated pipette, exactly 0.2 ml of each of the prepared standards (under D) and place in separate depressions of a white porcelain spot plate. Do likewise with the unknowns.

Add to each 4 drops of solution C; next, add 4 drops of solution B. Stir each with a small glass rod and compare the intensity of the violet color of each of the unknowns with that produced by the standards.

FACTORS AFFECTING THE SOLUBILITY OF COPPER

From analyses of different soils having essentially the same history of potato culture, it was evident that the amounts of copper extracted by the universal solution depended on factors other than the total quantities of bordeaux applied. Since organic matter is known to fix copper, the soils were analyzed for organic content by Schollenberger's method (3). Table 1 gives the amounts of copper extracted from 10 potato soils using the procedure described.

TABLE 1.—*Amounts of copper extracted from potato soils by method described.*

Field	Years in potatoes	Organic matter, %	Soluble Cu^{++}, p.p.m.
M	12	2.66	60
H	12	5.95	3
R	10	3.24	15
S	10	2.81	10
T	Probably 10	2.04	10
C	Probably 6	3.59	10
L_5-31	1	5.72	Trace
L_5-31	After 6 more	5.93	3
L_5-7	1	7.62	0
L_5-7	After 6 more	7.17	1

DISCUSSION

EFFECT OF ORGANIC MATTER

The original problem field was designated M. Based on the grower's statements, a nearby field, H, had received the same amount of copper. The latter had only one-twentieth as much soluble copper as the former. It will be noted, however, that the percentage of organic matter in the soil from field H is over twice as high as in that of M. Three other commercial potato farms are labeled R, S, and T. All three had been planted to potatoes almost continuously for 10 seasons all are on light soils, all contained roughly equal amounts of

organic matter, and all contained approximately the same concentrations of soluble copper. Field C, adjacent to field M, had about one-third more organic matter and only one-sixth as much soluble copper. L_5–7 and L_5–31 are experimental potato plots sampled after 1 and after 7 years of potato culture, respectively. The higher organic matter content of L_5–7 as against that of L_5–31 again resulted in a lower concentration of soluble copper.

The organic matter content of these soils had more influence on concentrations of soluble copper, as extracted by this method, than did the total quantity applied, as judged by the history of the fields.

TYPE OF EXTRACTANT

In order to determine whether the greater quantity of organic matter in the soil of field H was responsible for its greater fixing power, and also to ascertain whether fields H and M contained approximately equal quantities of elemental copper, both soils were treated with a strong mineral acid, 0.37N sulfuric acid, instead of the universal solution. That the organic matter was more strongly attacked was evident as a very dark-colored extract was obtained. This extract was evaporated to dryness, gently ignited to remove the organic matter, and solution A added to the residue. The copper was determined as previously outlined, with the following results:

Field	Soluble copper extracted, p.p.m. By Solution A	By 0.37N H_2SO_4
M	60	120
H	3	120
C	10	40

Thus, soils M and H contained nearly the same amount of copper soluble in a strong mineral acid in marked contrast to the widely different quantities removed by the universal solution. The smaller amount of copper extracted from soil of field C by the strong mineral acid, 40 p.p.m., reflects the smaller total quantity of bordeaux applied.

SUMMARY

A semi-quantitative test for copper has been developed, based on the qualitative test described by Feigl. The procedure is simple and may be adapted easily for use with the Morgan universal soil testing system or other of the so-called quick tests designed to determine copper in plant tissue and in soils.

Results obtained with the procedure on soils from several Connecticut commercial potato fields showed that the organic matter of such soils exerted a very pronounced effect on the solubility of the copper that had been previously applied as bordeaux spray. Those soils having a higher percentage of organic matter contained a much smaller amount of soluble copper even though receiving approximately equal amounts of that element.

LITERATURE CITED

1. FEIGL, FRITZ. Qualitative Analysis by Spot Tests. Elsevier Nordemann. 1939.
2. MORGAN, M. F. Chemical soil diagnosis by the universal soil testing system. Conn. (New Haven) Agr. Exp. Sta. Bul. 450. 1941.
3. SCHOLLENBERGER, C. J. Determination of soil organic matter. Soil Sci., 59: 53–56. 1945.

Development of Early Maturing Wilt-Resistant Strains of Korean Lespedeza[1]

CARROLL P. WILSIE AND H. D. HUGHES[2]

THE introduction into the United States, in 1919, of the early maturing annual lespedeza, *Lespedeza stipulacea*, later designated and distributed as Korean lespedeza, is recognized as of great agricultural significance.

At a much earlier date, probably prior to 1846, common lespedeza, *Lespedeza striata*, had been introduced into the cotton belt from Japan and had rapidly gained popularity as an acid-tolerant legume adapted to relatively poor land. Its greatest value, perhaps, has been when used for pasture in mixture with grasses, the annual legume carrying over from year to year by volunteering from shattered seed. The length of season required for seed maturity, however, is such that common lespedeza is not well adapted north of Kentucky, southern Illinois, and southern Missouri.

Korean lespedeza was found to be sufficiently early to reseed from year to year as far north as the Iowa-Missouri line, with limited value in extreme southern Iowa. The fact that over 10 million acres of lespedeza are reported from Missouri attests to the outstanding value of this legume.

The need in Iowa for a lespedeza sufficiently early to carry over dependably from year to year from shattered seed has long been recognized, especially for the southern half of the state.

An early maturing strain selected by the Division of Forage Crops and Diseases of the U. S. Dept. of Agriculture, designated as F.C. No. 19604 and later called Early Korean lespedeza, was released in 1936 after having been tested through a period of years by the Iowa, Illinois, and Missouri agricultural experiment stations. In 1937, just one year after its release, plantings of Early Korean 19604 at Arlington, Va., as well as in scattered Illinois, Missouri, and southern Iowa plantings showed evidence of serious disease damage. This disease was later identified as a bacterial wilt caused by the organism *Phytomonas lespedezae*, which apparently is both seed and soil borne.[3] Early symptoms of infection are dark water-soaked spots, extending parallel to the leaflet veins. In hot, bright weather this stage is of short duration, the infected leaves soon becoming brown, dried, and curled. Because of the marked susceptibility of the Early Korean 19604 strain to this disease, and the severe damage it caused, a search was begun for resistant material.

H. D. Hughes observed in the summer of 1938 occasional small clusters or families of lespedeza plants growing along the highways in two separate locations in the vicinity of Cedar Rapids (east central

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[2]Research Associate Professor and Research Professor, respectively.

[3]AYERS, T. T., LEFEBVRE, C. L., and JOHNSON, H. W. Bacterial wilt of lespedeza. U. S. D. A. Tech. Bul 704. 1939.

Iowa). It was learned that the State Highway Department had seeded Korean lespedeza generously along these highways a few years previously, but it had disappeared entirely except for these occasional families, each of which probably had resulted from the reseeding of an individual early maturing plant.

In the fall of 1938, seed was gathered enmasse from 73 of these families, the assumption being made that the plants constituting each family probably were the progeny of a single self-fertilized individual parent, and would, therefore, perform as a pure breeding line.

In April, 1939, row plantings of the 73 lots of seed were made, both at Ames (central Iowa) and at Albia (southern Iowa), together with check plantings of standard Korean and Early Korean 19604. At the same time, seed was supplied to the Missouri Agricultural Experiment Station and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture. The Iowa plantings were observed for growth habit, vigor, earliness of maturity, variability, and apparent susceptibility to wilt.

In order to obtain a more effective evaluation of wilt susceptibility, the plants at Ames were clipped in early July and the freshly cut leaf and stem surfaces sprayed with a bacterial suspension of the wilt organism. This inoculation, while not entirely satisfactory, did increase the amount of infection, making possible a more reliable comparison of wilt damage than otherwise could have been made.

All of the strains were earlier than the standard Korean lespedeza but none of them quite as early as Early Korean 19604.

Almost without exception little or no variability between the plants of a given family could be detected, making any further selection within these lines ineffective. In only one or two instances was variability observed.

At the end of the growing season, seed was harvested from the more vigorous, early maturing strains, especially from those that showed little or no evidence of wilt damage. The whole nursery was allowed to reseed itself and a rating on maturity given all selections, based on the amount of volunteer growth that appeared the following spring as well as on the date of blooming in the previous season. Because of the production of apetalous flowers, exceedingly common in Korean lespedeza in some seasons, it sometimes is very difficult to determine just when a plant starts to bloom and to set seed.

The selections made in 1938 were grown in 1939, 1940, and 1941 in observational nurseries, with particular attention given to vigor of growth, earliness of maturity, and relative freedom from bacterial wilt.

STRAIN TRIALS

Beginning in 1942, after many of the original selections had been eliminated, replicated trials were inaugurated to determine wilt reaction, relative maturity, and yield of both forage and seed. In 1944 a very early killing freeze in September prevented full maturity.

The forage yields reported are on the basis of tons per acre of air-dry material. The plots consisted of either one or two rows, each 16

feet in length, spaced 3 to 3½ feet apart. Small broadcast plots also were planted during three of the seasons, though replicated yields were obtained from these in only one season.

A summary of the data obtained in 1942, with four replications of 18 strains, is given in Table 1. Indexes on relative wilt infection and earliness of maturity are included. Field notes indicated that in this particular season considerable bacterial wilt was present in all strains and varieties. A number of strains, however, were relatively early in maturity and showed little or no greater wilt infection than the standard Korean when the infection of the Early Korean 19604 was extremely heavy. Strains 6 and 48–1 led in forage yield, while Early Korean 19604 was one of the lowest producers, due primarily to wilt damage.

TABLE 1.—*Bacterial wilt index, maturity index, and forage yield of Korean lespedeza strains at Ames, Iowa, in 1942.*

Strain	Bacterial wilt index July 20 and Aug. 29, 1942*	Maturity index Sept. 24, 1942†	Tons of dry forage per acre‡	Most promising
48-1	2.2	4.5	1.62	X
39	2.8	6.0	1.12	X
Standard Korean	3.0	3.8	1.22	X
26	3.8	5.3	1.53	X
50	3.8	5.5	1.33	X
6	4.1	5.8	1.74	X
23	4.3	4.5	1.19	—
36	5.5	6.3	1.22	—
66	5.8	6.0	1.25	—
25	5.8	6.3	1.10	—
20	6.0	6.0	1.10	—
73	6.5	5.5	1.06	—
55	7.0	5.5	0.60	—
81	7.5	5.8	1.00	—
80	7.8	6.3	0.98	—
79	8.5	6.0	0.92	—
56	8.5	6.3	0.65	—
Early Korean 19604	9.0	7.3	0.83	—

*Index on scale of 1 to 9; 1 least, 9 most.
†Index on scale of 1 to 9; 1 least, 9 most.
‡Differences of 0.31 ton per acre are significant at the 5% level.

In 1943 the lespedeza trials were located on a flat area of Webster silt loam, extending into silty clay loam. The soil in this field was relatively high in carbonates, generally referred to as "alkali spots," in the central corn belt, typical of much of the north central Iowa Webster high lime soil. The high carbonate content of the soil evidently interfered with normal mineral nutrition, and with the exceptions of strain 39, all selections became chlorotic and made an extremely poor growth, many plants not even surviving until the end of the season. The one strain 39, however, made a normal growth

under these high lime conditions, remaining green and vigorous all through the season. Yellowing of all other strains was shown to be associated with a deficiency of iron and spraying the affected plants with iron sulfate resulted in the rapid partial regaining of the normal green color.

The extremely early killing frost which occurred in September of 1944 made it impossible to get records believed to be sufficiently meaningful to report.

In 1945 the strain trial was limited to nine entries, including the Early Korean 19604 as a check for wilt and maturity. A summary of data on wilt reaction, forage yields both in rows and broadcast plots and seed yields for six replications is given in Table 2.

TABLE 2.—*Bacterial wilt index and yield of forage and seed of lespedeza strains in 1945 at Ames, Iowa.*

Strain	Bacterial wilt index*	Tons of dry forage per acre		Pounds of seed per acre§
		Rows†	Broadcast‡	
39	1.4	1.25	2.34	327
48-1	1.4	1.61	2.42	278
26	1.8	1.70	2.19	433
6	2.0	1.51	2.25	392
50	2.4	1.53	2.30	367
81	4.0	1.40	2.10	387
14	4.4	1.41	2.18	310
66	4.9	1.16	1.70	329
Early Korean 19604	8.8	0.35	1.15	185

*Index on scale of 1 to 9; 1 least, 9 most.
†Differences of 0.24 ton are significant at the 5% level.
‡Differences of 0.25 ton are significant at the 5% level.
§Differences of 57.1 pounds are significant at the 5% level.

In 1946 the strain trial was similar to that of 1945 with the exception that strain 66 was dropped because of its previous mediocre performance. The broadcast plots were exceptionally weedy and had to be clipped several times during the summer to prevent weeds from setting seed. Comparative data on wilt reaction and yield obtained from the row plots only are summarized in Table 3.

TABLE 3.—*Bacterial wilt index and yield of forage and seed of lespedeza strains at Ames, Iowa, in 1946.*

Strain	Bacterial wilt index*	Tons of dry forage per acre†	Pounds of seed per acre‡
6	1.3	1.32	517
39	1.3	1.70	716
48-1	1.7	2.39	815
26	2.3	2.42	1,016
50	2.3	2.31	1,001
81	3.0	2.10	1,030
14	3.7	1.92	887
Early Korean 19604	4.3	1.32	517

*Index on scale of 1 to 9; 1 least, 9 most.
†Differences of 0.20 are significant at the 5% level.
‡Differences of 122.7 pounds are significant at the 5% level.

Strains remained in much the same order as in 1945 when ranked in yield of forage and seed, although the seed yields in 1946 were exceptionally high because of a long autumn which permitted normal maturity in most selections.

A summary of forage yields for the eight strains included in four trials in three seasons is given in Table 4.

TABLE 4.—*Yield in tons of dry forage per acre and maturity rating for lespedeza strains during a 3-year period at Ames, Iowa.*

Strain	1942 rows	1945		1946 rows	Average for 3 years*	Maturity rating
		Rows	Broadcast			
48-1	1.62	1.61	2.42	2.42	2.02	4
26	1.53	1.70	2.19	2.44	1.96	2
6	1.74	1.51	2.25	2.28	1.94	2
50	1.33	1.53	2.30	2.33	1.87	3
81	1.00	1.40	2.10	2.12	1.65	2
39	1.12	1.25	2.34	1.71	1.60	3
14	—	1.41	2.18	1.93	1.38	3
Early Korean 19604	0.83	0.35	1.15	1.34	0.92	1

*Differences of 0.13 ton per acre (for 3-year average yields) are significant of the 5% point.

Marked differences in yield of forage were obtained consistently through the several seasons, comparing a number of selections with the Early Korean 19604 strain. None of these selections is as early as Early Korean 19064, but all of them have reseeded successfully as far north as central Iowa in each of the past eight years, with the exception of 1944 when an exceptionally early killing frost occurred.

GREENHOUSE WILT EXPERIMENTS

Field ratings of wilt resistance, while helpful, are not accurate nor satisfactory. In seasons of light infection plants may not show clear-cut symptoms of wilt, while in some years marked killing of plants with consequent stand reduction takes place. In a period of moist cloudy weather, the early symptoms (water soaked areas rectangular in shape and extending between leaf veins) may be clearly visible, while in dry hot weather the first noticeable symptoms may be the browning and drying of the leaves on a portion of the plant or on the whole plant.

To obtain more critical data studies using artificial inoculation were started in the greenhouse in the fall of 1941. Cultures were isolated from diseased material and were maintained by the Department of Botany and Plant Pathology.[4] Cultures were supplied also by the Division of Forage Crops and Diseases.

Seedlings were established in flats, using sterile soil and both sterilized and nonsterilized seed. The plants were grown under con-

[4]Appreciation is expressed to Dr. G. C. Kent, formerly of the Botany and Plant Pathology Department, Iowa State College, for his generous cooperation. The authors are indebted also to Marshall Evans, formerly Research Associate, Iowa Agricultural Experiment Station, for assistance in the wilt inoculation studies.

ditions favoring rapid growth and the development of succulent tissues. When approximately 3 to 4 inches in height, half of the plants were inoculated, using needles to scratch and puncture the leaf surface and to apply the bacterial suspension at the same time. Following inoculation the temperature and relative humidity were kept fairly high (temperature 75° to 85°F, relative humidity 75 to 80%) in an effort to obtain a high degree of infection.

Results obtained using this technique were not satisfactory. Although some infection occurred, the method did not provide an accurate means of evaluating selections of lespedeza for resistance to bacterial wilt. Attempts to obtain more uniform infection by adjusting the temperature, humidity, and soil moisture were relatively unsuccessful.

In 1944 a new technique was used, similar to that used in inoculating alfalfa seedlings with bacterial wilt. Seedlings were grown in sand cultures in flats until they reached a height of approximately 4 inches, when they were removed, washed free of sand, and either the tops or roots cut, holding the plants under the surface in a suspension of the wilt bacteria. The plants were then transplanted into flats or pots and allowed to grow for several weeks at a temperature of approximately 70° to 75° F. Care was taken to see that all plants were well inoculated with the proper *Rhizobium* culture so that normal rapid growth would take place.

Wilt symptoms were recorded, beginning approximately 4 weeks after inoculation, with a recording of the percentage of the first trifoliate leaves that showed visible symptoms of infection. At approximately weekly intervals for a period of 5 weeks further wilt readings were made, recording only the percentage of plants that had died.

TABLE 5.—*Comparison of several strains of lespedeza with respect to the percentage of plants killed following inoculation with Phytomonas lespedeza, planted Nov. 20, 1944, inoculated and transplanted Jan. 4, 1945.**

Date	Symptom	Roots cut in bacterial suspension†				Tops cut in bacterial suspension‡			
		Strain 6, %	Strain 39, %	Strain 81, %	Early Korean 19604, %	Strain 6, %	Strain 39, %	Strain 81, %	Early Korean 19604, %
Jan. 31	First trifoliate leaves infected	10	14	20	8	50	65	60	80
Feb. 5	Plants dead	2	0	10	6	0	5	25	53
Feb. 9	Plants dead	2	6	24	6	0	5	35	53
Feb. 15	Plants dead	3	12	36	10	15	5	55	87
Feb. 26	Plants dead	5	22	42	24	40	25	85	100
Mar. 8	Plants dead	12	27	62	64	63	60	90	100

*Check plants not inoculated showed no symptoms of wilt.
†Fifty plants of each strain inoculated.
‡Twenty plants of each strain inoculated.

Data obtained for the four strains of lespedeza used in this experiment are given in Table 5.

The data indicate that cutting the tops under the bacterial suspension produced a more severe infection than that produced by cutting the roots. Results obtained following the root inoculation appeared to be somewhat comparable to those obtained in field ratings of wilt resistance over a period of years and this comparison is shown in Table 6.

TABLE 6.—*Comparison of wilt resistance of several lespedeza strains as indicated in greenhouse and field studies.*

Strain	Percentage of resistant plants in greenhouse study	Wilt resistance index base on 5-year average of field observations*
39	73	2.0
6	88	2.1
48-1	—	2.5
26	—	2.7
50	—	3.4
14	—	3.9
81	38	4.2
Early Korean 19604	36	7.1

*Index on scale of 1 to 9; 1 least, 9 most.

Striking differences in susceptibility to wilt were indicated, especially among the four strains in the greenhouse trial. Of these, strains 6 and 39 showed a high degree of resistance, while strain 81 and Early Korean 19604 were susceptible.

Strain 81, developed from a single plant selected in the breeding nursery in 1938, appeared very promising at Ames in certain seasons. It is early in maturity and has given good yields of seed and fair yields of forage. Under central Iowa conditions, however, it has not shown satisfactory wilt resistance in most seasons. The Missouri Experiment Station has reported strain 81 to be among the best in their trials at Columbia. Its performance has been promising also at Beltsville, Md., as reported by the Division of Forage Crops and Diseases. In neither of these places, however, has wilt damage been so great as it has been at Ames during the past few years. Further research is needed with regard to the distribution and severity of the disease, the pathogenicity of the causal organisms, and the development of standardized technique for studying wilt resistance.

NEW STRAINS RELEASED

By 1944 the information on the different selections seemed to be sufficiently specific to justify the increase and release of one or more of these early disease-resistant strains. Three strains, nos. 6, 39, and 48–1, were selected for increase, to be distributed under the designations Iowa 6, Iowa 39, and Iowa 48, respectively. The seed increase of new varieties from the Iowa Agricultural Experiment Station is handled by the Committee for Agricultural Development, which contracts with selected individual growers.

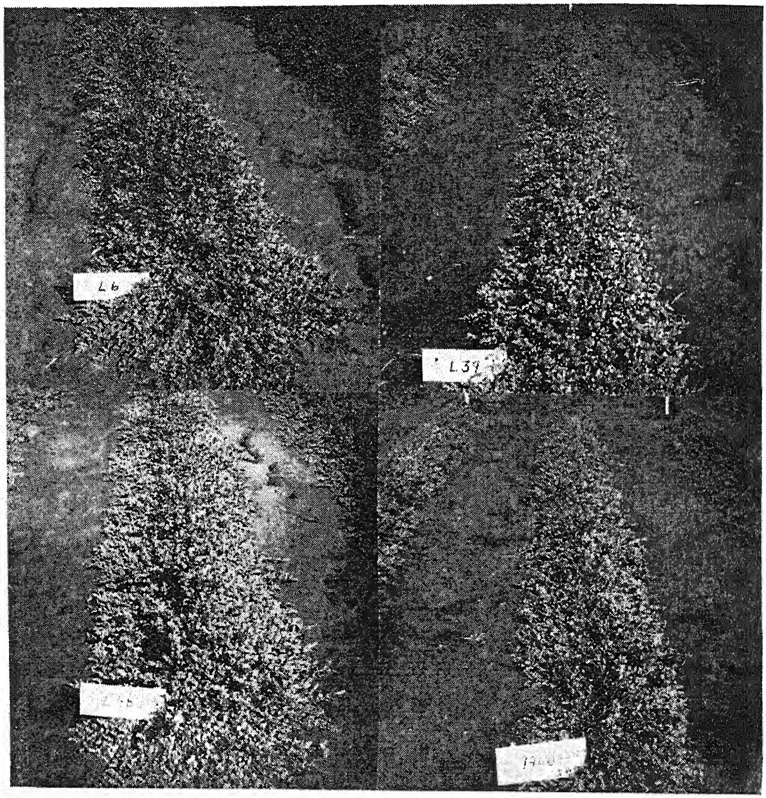

FIG. 1.—Early maturing strains of Korean lespedeza growing in the nursery at Ames, Iowa, in 1945. *Upper left*, Iowa 6; *upper right*, Iowa 39; *lower left*, Iowa 48; *lower right*, Early Korean 19604 showing wilt damage.

Iowa 6 is vigorous, early in maturity, and satisfactory in wilt resistance. Iowa 39 is somewhat less vigorous and slightly later in maturity than strain 6. It has a characteristic grayish green color and has the unusual ability to grow on high lime soils, where all the other strains of lespedeza failed, as previously indicated. Iowa 48 (from 48-1) is one of the most vigorous and productive of all the strains tested. It is a little later in maturity than the other two, but is distinctly earlier than the standard Korean. It should be well adapted to the southern part of Iowa and other like climatic areas.

Row plantings of these strains, together with Early Korean 19604, are illustrated in Fig. 1.

The increase of strains Iowa 39 and Iowa 48 is just getting under way. Some 5,000 pounds of seed of Iowa 6 were available by the fall of 1946. In order to obtain further increase quickly this was offered farmers in southern Iowa counties who would grow it for seed in 1947 under conditions meeting the state seed certification standards. It is anticipated that rather good stocks of seed may be available for general planting in 1948.

Anhydrous Ammonia Retention by Soils as Influenced By Depth of Application, Soil Texture, Moisture Content, pH Value, and Tilth[1]

M. L. JACKSON AND S. C. CHANG[2]

ANHYDROUS liquid ammonia, the most concentrated of nitrogenous fertilizers, has been used as a nitrogenous fertilizer since the early 1930's, beginning in California (1).[3] This material, pure NH_3, is liquified under pressure and stored in steel tanks at a pressure of 135 pounds per square inch at ordinary temperatures. The commercial compound contains 81.5 to 82.5% of nitrogen and is the least expensive form of fixed nitrogen (2). Its present use as a fertilizer is largely in the irrigated region, the NH_3 gas being dissolved in irrigation water, but direct application of NH_3 to the soil is being studied at several agricultural experiment stations. A few private firms in the Corn Belt are developing pumps and machines with a view to direct application to the soil.

The most critical technical problem in the use of anhydrous ammonia as fertilizer is the rapidity of sorption by the soil immediately after its application and extent of loss by diffusion into the atmosphere. Theoretically, acid soils should hold NH_3 against volatilization more strongly than neutral soils. Other soil factors, such as moisture content, clay content, and tilth, would also be expected to exert some influence on NH_3 sorption.

The purpose of this investigation was to determine the efficiency of uptake (and extent of loss) of NH_3 placed at various depths in soils of various texture, pH value, lime content, moisture content, and tilth, at rates of application commonly used in agricultural practice and at somewhat higher rates.

LITERATURE REVIEW

The fact that most plants can assimilate fixed nitrogen in the form of NH_4^+ as effectively as NO_3^- is generally recognized. In 1889, Muntz and others (9) showed that beans, barley, hemp, and corn were able to grow in the absence of nitrate additions, but he did not prove conclusively that the ammonium salt was the sole source of nitrogen. In 1898 to 1900 Mazé and later Prianischnikow (9) showed that corn can utilize ammonium salts as readily as nitrates. Since then a voluminous literature has been accumulated on the relative value of ammonium salts and nitrates. Miller (9) has reviewed this subject exhaustively in his book. He states that the two most important factors governing the relative value of ammonium salts and nitrates are reaction of the medium and the age and kind of

[1]Journal Paper No. 291, Purdue University Agricultural Experiment Station, Lafayette, Ind. Contribution from the Department of Agronomy. Received for publication March 19, 1947.

[2]Formerly Associate Professor of Agronomy, Purdue University, now Associate Professor of Soils, University of Wisconsin, and formerly Chinese Government sponsored agriculture technician under trainee status at Purdue University, now Soil Chemist, Taiwan Agricultural Research Institute, Taipeh, Taiwan, China, respectively. Grateful appreciation is expressed for the cooperation of the Tennessee Valley authority through Dr. R. J. Jones, Agricultural Relations Office, in furnishing a cylinder of anhydrous ammonia for these studies.

[3]Numbers in parenthesis refer to Literature Cited", p. 632.

the plant. So far as soil reaction is concerned, plants show preferential response to ammonium salts in the neutral range of soil pH values.

According to MacIntire, *et al.* (8), the manurial usage of ammonium hydroxide form of nitrogen was described as long ago as 1852 in Johnstone's writings (6). In the United States, the possibility of use of NH_4OH as fertilizer was pioneered at the New Jersey Agricultural Experiment Station by Tiejens and Robbins (12). In their sand culture experiments with a number of crops they concluded that ammonia was most effectively assimilated by plants at pH 7.0 or above and that nitrates were relatively more effectively assimilated at pH 4 to 5. With the tomato, ammonia at pH 8.0 was assimilated more rapidly than nitrate at pH 4 or 6. Ammonium hydroxide was a much better source of nitrogen than either ammonium sulfate or calcium nitrate for tomato and soybean. Chapman (4) used NH_4OH solution as fertilizer for Sudan grass in his experiments with phosphorus availability in calcareous soils. Recently MacIntire, *et al.* (8), in studying the response of sudan grass to NH_4OH, found that, for one crop of Sudan grass, surface addition of NH_4OH at rational rates proved virtually as efficacious as equivalent amounts of the sulfate or nitrate.

Fertilization with the anhydrous form of ammonia introduced in irrigation water in experiments by Waynick (13) was started in the early 1930's in California. Several experimental studies of this mode of application have been reported since. In supplying ammonia to peaches and prunes at different seasons, Forde and Proebsting (5) found that nitrogen applied as NH_3 in irrigation water behaves essentially the same as $(NH_4)_2SO_4$. Waynick (13) states that NH_3 has the advantage of liberating Ca, Mg, and K from the soil for plant use, in liberation of phosphoric acid after nitrification, and of producing less soil acidity per unit of nitrogen. Rosenstein (11) reported high availability of NH_3 to various kinds of plants, including cereals, vegetables, and fruits.

The experimental results on extent of loss of NH_3 in direct application of anhydrous ammonia to soil are scant. Noticeable aroma due to volatilization losses in connection with field applications of aqueous ammonium hydroxide has been noticed by some observers. MacIntire, *et al.* (8) found that the yields obtained with ammonium hydroxide were sometimes less than with nitrate and sulfate, and thought this might be attributed to loss of NH_3 by volatization during application of NH_4OH. Loss potential of NH_3 would be expected to exceed that of NH_4OH. Andrews *et al.*, (3), however, in their investigation in connection with direct application of anhydrous ammonia, found that its efficiency so far as shown by crop response was as favorable as NH_4OH_3 if applied so as to control nitrification and subsequent leaching adequately. They concluded that soil with a pH as high as 8.0 or above will retain NH_3 form of nitrogen but nitrification is faster than in soils of lower pH values. They thought no difficulty would arise in use of NH_3 as a result of nonsorption in calcareous alkaline soils. Their machinery employs a disc cover to follow the knife injector. On the other hand, California workers (7) found the application of anhydrous ammonia should be at a depth from 2 inches to 18 inches or more according to the characteristics of the soil so as to insure complete sorption.

Fundamentals of the sorption of NH_3 gas by soils was investigated by Pinner (10). His study was mainly directed to the theory of sorption of gas and liquid and the results are of limited value in interpretation of losses from soil.

The purpose of the present study was to evaluate the possible NH_3 loss potential due to volatilization. Nitrification and leaching, which have been studied by Andrews, *et al.* (3), were not included in this study; neither were included factors of "dispersion" (non-banding) and consequent competitive use by soil microorganisms as noted by W. Fitts and associates.[4]

EXPERIMENTAL TECHNIQUE

Approximately 1 kilogram of soil was placed in a 800-ml beaker, giving a "plow-layer" depth of about 5 inches. At the center of this soil, a glass injection tube 1 cm in diameter was inserted to a depth which corresponds with the depth of ammonia application contemplated. The lower end of the injection tube was covered with a little glass wool so as to prevent the soil entering the tube. The beaker containing the soil was placed in a vacuum desiccator with the injection tube directly under the central stopper hole. Suction applied at the side hole provided a means of

[4]Personal communication, 1946.

evacuating the desiccator of air through an acid trap for collection of the escaping ammonia (Fig. 1). The soils selected for use in this experiment were a heavy soil, cultivated Crosby silt loam, and a light sand, Plainfield sand. Beach sand was also included for standardization of the technique and for reference.

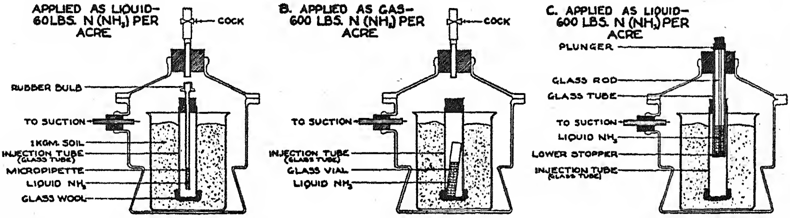

FIG. 1.—Apparatus used for determination of the anhydrous ammonia nitrogen gas sorption in soil.

RATES OF APPLICATION

Two rates of application were used. The lower rate was 60 pounds of elemental nitrogen, or 75 pounds of anhydrous ammonia per acre, the ratio of anhydrous ammonia to soil thus being 187 p.p.m., or 0.187 grams NH_3 per kgm of soil, or approximately 0.3 ml per kgm (the sp. gr. of anhydrous ammonia is 0.618). In the experiment, the assumptions were made that the anhydrous ammonia is drilled in the field in lines spaced 15 inches apart and that the weight of surface soil per acre is 2 million pounds. Since the 800-ml beaker is approximately 3 inches wide, the actual rate of application per unit weight of soil in the beaker was five times as much as it would be if broadcasted uniformly over the field. In the locality of contact of the ammonia with the soil, the rate of application might be a thousand times the equivalent uniform broadcast rate. The higher rate used was ten times the lower rate, 600 pounds of elemental nitrogen or 750 pounds of anhydrous ammonia per acre, applied in the same way.

In experimentally dispensing the anhydrous ammonia taken from the steel cylinder, the pressure was released through a nozzle. Since the rapid evaporation of anhydrous ammonia deprives it of large amounts of heat, its temperature quickly drops below its boiling point $-33.35°C$ and the liquid flows out into a beaker, maintaining liquid form under atmospheric pressure. A measured volume was first introduced into the injection tube by means of special pipettes or vials. The pipette was dipped into the liquid ammonia until its temperature reached that of the liquid ammonia, and the boiling of liquid ammonia ceased. A definite volume of the liquid ammonia was measured out, and the pipette dropped into the injection tube (Fig. 1A). The tube was closed with a small rubber stopper. When anhydrous ammonia was to be applied to the soil surface, the pipette was fitted on the top stopper of the desiccator with its tip touching the surface of the soil. In case of using a vial for handling a larger amount of anhydrous ammonia, the anhydrous ammonia was poured into the vial to cool it and then added to volume. The various set-ups are shown in Fig. 1A, B, and C.

The desiccator was subjected to repeated exhaustion by a strong water aspirator pump, requiring about 2 minutes. This was followed by admission of air at the top stopper. This process was continued cyclicly, with 2½ minutes as a cycle, for 30 minutes (12 cycles). A preliminary trial had shown that recovery of NH_3 was 93% in this time when a dry beach sand was used as the "soil".

The percentage NH_3 escaping of that applied to dry quartz beach sand at 4 inches depth at a rate of 75 pounds anhydrous ammonia per acre is given in Table 1. It is shown that suction in this way is rather effective in removing the NH_3 not sorbed by the soil and that after 30 minutes suction, little NH_3 was recovered in the next 1½ hours, whence the adoption of a 30-minutes suction period (12 cycles). The strength of the standard H_2SO_4 solution in the acid trap was $N/14$ or $1N$ according to the quantity of NH_3 expected to escape. The excess of acid was back-titrated with standard NaOH solution, brom phenol blue being used as indicator. Evidently even dry beach sand adsorbs an appreciable quantity (14 to

20%) of NH_3. It is believed that this suction technique placed a greater loss potential on the soil than would be expected to occur in the field. Evacuation to approximately 0.02 atm causes expansion of the gas within the pore space to 50 times its original volume and thus 49/50 of the ammonia gas present would be trapped in the standard acid in *each cycle.*

TABLE 1.—*Percentage of NH_3 escaping with time of aspiration and evacuation.**

Time of aspiration	Percentage NH_3 lost of that added
5 minutes (2 cycles)	68
10 minutes (4 cycles)	77
30 minutes (12 cycles)	81
60 minutes (24 cycles)	84
120 minutes (48 cycles)	86

*Anhydrous ammonia applied at the rate of 75 pounds per acre to dry quartz beach sand.

In order to test the reproducibility of the procedure, replicate determinations were made in some treatments (Table 2). In no case was the range of variation greater than 5.5% or 3.3 pounds per acre of total nitrogen added, which was considered satisfactory. Most of the data in this investigation were therefore obtained from a single determination. In making interpretations, a difference between two results of more than about 5% or 3.3 pounds of the total 60 pounds of nitrogen added can be considered significant.

TABLE 2.—*Replicate determinations of nitrogen lost from air-dry, cultivated Plainfield sand.*

Replication	Nitrogen escaped of that added, 60 lbs. per acre							
	Excessively limed, pH 7.7						Moderately limed	
	NH_3 applied at 0 in.		NH_3 applied at 1 in.		NH_3 applied at 2 in.		NH_3 applied at 2 in.	
	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%
1	43.8	73	16.4	27.0	9.1	15.2	3.4	5.7
2	44.4	74	16.5	27.5	10.7	17.8	1.4	2.4
3	—	—	—	—	12.0	20.0	3.5	5.8
4	—	—	—	—	—	—	3.9	6.5
5	—	—	—	—	—	—	4.8	7.9

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results are recorded in Tables 3 and 4, and summarized in Fig. 2. From the practical standpoint, the depth of application is the most significant factor in insuring complete sorption against gaseous escape. If the anhydrous ammonia is applied at from 1 to 4- inch depths in the soil so that the NH_3 can get contact with a considerable amount of soil before it diffuses into the atmosphere, the soil can sorb a tremendously large amount of NH_3. Results reported in Table 3 and Fig. 2 show that if the soil is of intermediate texture, moisture content, and pH value, an application of 60 pounds of N per

TABLE 3.—*Escape of ammonia nitrogen as influenced by texture, moisture content, and pH value, at various depths of application in two soils.*

Soil moisture content, treatment, and pH value	Nitrogen escaped expressed as pounds per acre and percentage of that added, with two rates of application													
	60 lbs. N per acre applied as liquid at depth of										600 lbs. per acre applied at depth of 4 in. in form of			
	0 in.		0.5 in.		1 in.		2 in.		4 in.		Gas§		Liquid¶	
	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%
Beach sand (control):														
Air-dry	56	93	—	—	—	—	54	90.5	48.5	81	400	67	540	90
Field-moist (7.7%)	48.5	81	—	—	—	—	17.5	29.3	5.0	8.4	16	2.7	57	9.5
Plainfield sand:														
On samples from cultivated field (pH 6.0)*														
Air-dry	36	58	—	—	9.8	16.5	3.5	5.7	0.0	0.0	96	16	156	26
Field-moist (9.1%)	29	49	—	—	3.7	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0	0
Excessively limed† (pH 7.7%):														
Air-dry	44	74	—	—	16.5	27.5	10.6	17.7	0.0	0.0	158	28	200	33.6
Field-moist (9.1%)	32	53	—	—	6.9	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0	0
Crosby silt loam:														
Samples from cultivated field (pH 6.4)*														
Air-dry	26.7	45	17.6	29.4	7.2	12	0.0	0.0	0.0	0.0	0.0	0.0	11	1.7
Field-moist (15.3%)	23.2	39	—	—	2.1	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Excessively limed (pH 7.6)†														
Air-dry	38.5	64	22.3	37.1	14.4	24.2	3.4	5.6	0.0	0.0	0.0	0.0	26	4.4
Field-moist (15.9%)	38.0	63	—	—	11.6	19.3	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Na_2CO_3-treated (pH 10.5)‡														
Air-dry	50	84	—	—	—	—	—	—	0.0	0.0	52	8.7	60	10.0
Field-moist (18.9%)	36	60	—	—	—	—	—	—	0.0	0.0	0.0	0.0	0	0.0

*Samples from cultivated soil, limed 10 years previously.
†One part of precipitated $CaCO_3$ mixed with ten parts of the cultivated soil.
‡One part of reagent Na_2CO_3 mixed with ten parts of the cultivated soil.
§As shown in Fig. 2B. ¶As shown in Fig. 2C.

TABLE 4.—*Escape of ammonia nitrogen as influenced by size of soil aggregates.*

Aggregate size	Nitrogen escaped expressed as pounds and percentage of that added with an application of											
	60 lbs. nitrogen per acre, applied at a depth of										600 pounds nitrogen per acre at depth of 4 in.	
	0 in.		0.5 in.		1 in.		2 in.		4 in.			
	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%
Crosby Silt Loam—Field Sample*												
Fine aggregate (<2mm)	26.7	44	17.6	29	7.2	12	0.0	0.0	0.0	0.0	11	1.7
Coarse aggregate (2 to 6mm)†	29.0	48	21.0	35	10.6	18	0.8	1.3	0.0	0.0	7.8	1.3
Crosby Silt Loam—Excessively Limed (pH 7.6)‡												
Fine aggregates (<2mm)	38.5	64	22.3	32	14.4	24	3.4	5.6	0.0	0.0	26	4.4
Coarse aggregates (2 to 6mm)†	42.1	70	36	60	12.8	21	1.4	2.3	0.0	0.0	40	6.6

*Sample from cultivated soil, limed 10 years previously.
†<6-mm aggregates obtained through a 4-mesh per inch screen.
‡1 part of precipitated $CaCO_3$ mixed with 10 parts of cultivated soil.

acre in the form of NH_3 at a depth of 1 to 2 inches is completely sorbed and there is practically no loss by gaseous diffusion. Also, soils can retain at least 600 pounds of N per acre as NH_3 when it is applied at 4 inches depth. If the anhydrous ammonia is applied on the surface, a large portion of it would be expected to escape into the air. The amount which escaped ranged from 23.2 pounds to 56 pounds out of 60 pounds according to the nature of the soil. Surprisingly, over half of it was conserved under some conditions.

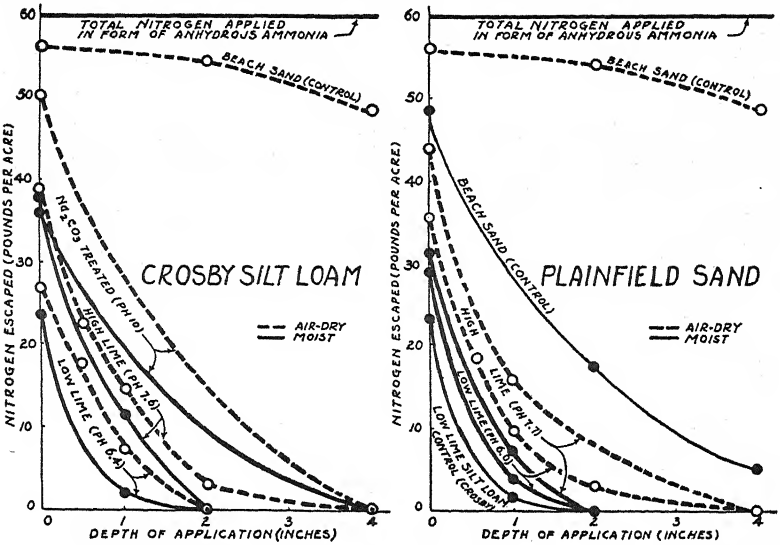

FIG. 2.—Losses of gaseous ammonia (expressed as nitrogen escaped) as influenced by depth of application in soil, soil texture, moisture content, and pH value.

The coarse-textured soil, Plainfield sand, retained the gaseous ammonia with approximately as great efficacy as did the finer textured soil, Crosby silt loam. This was especially true in the moist, neutral condition. Even in the air-dry condition, this sandy soil contains enough clay and organic matter, about 6 and 0.5%, respectively, to provide adequate sorption capacity for the NH_3. The beach sand control when dry lost the major share of the nitrogen applied but when moist retained approximately 80% of the nitrogen applied (Table 3 and Fig. 2). Apparently, a certain amount of sorption or reaction occurred even on siliceous material, since not all of the NH_3 could be evacuated from the dry sand (Fig. 2).

Whereas moisture was a dominating factor in the results with the beach sand control, the moisture content of the soils, air-dry as compared to field-moist, exerted only a slight effect. In general, at a 2-inch depth, the air-dry soil lost less than 5%, while the moist soil lost none. The 4-inch depth of application in soil resulted in complete conservation of NH_3 regardless of moisture content. Apparently, even a small clay content exerts a dominating influence, and the moisture

factor, over the range of variation expected in the field, can be neglected in practical applications of NH_3 as a fertilizer.

Increase in pH value, effected by the presence of free $CaCO_3$ or the alkalinity due to $NaCO_3$, did not prevent satisfactory retention of gaseous ammonia by the field-moist soils when the placement was at 2 to 4 inches depth, since 95 to 100% of it was retained. This was true even at the excessive rate of 600 pounds of N per acre. The calcareous condition nearly doubled the loss from dry Plainfield sand as compared to dry Crosby silt loam, with the application at a 2-inch depth, but the maximum loss was limited to 10 to 12% at this 2-inch depth. The loss was 0 at a 4-inch depth. The alkaline reaction brought about by Na_2CO_3 addition (10% of the soil weight) resulted in a marked decrease in retention of the surface-applied NH_3, of which 88% was lost. However, in spite of the alkalinity, total retention was effected when application was made at the 4-inch depth.

Coarse tilth did not interfere greatly with the efficacy of sorption in comparisons of aggregates of 2 to 6 mm diameter to fine soil (less than 2 mm) with an application depth of 2 to 4 inches (Table 4). The coarse aggregates lost appreciably more NH_3 than the fine soil at application depths of 0.5 to 1.0 inch. Satisfactory conservation of the NH_3 was achieved by the aggregates even at 600 pounds of N per acre rates (Table 4). The aggregates only 6 mm in diameter, while as coarse as small gravel, could not be used in predicting results with very cloddy soils. An unusually cloddy state of tilth would be expected to cause some loss of NH_3.

MECHANISMS OF NH_3 RETENTION BY SOILS

The mechanisms of the sorption of anhydrous ammonia were not directly investigated here, but on theoretical grounds, four mechanisms seem to be possible.

(a) In acid soils, the NH_3 will combine with hydrogen colloid (x) to form ammonium colloid as shown in the following equation

$$NH_3 + Hx \longrightarrow NH_4x \text{ (nonvolatile)} \qquad 1$$

(b) In neutral soils (pH 7), NH_3 combines with the soil colloid which is partially saturated with calcium but contains many weakly ionized hydrogen ions to form calcium ammonium colloid (reaction 2). This reaction is somewhat analogous to the reaction between mono-dicalcium phosphate ($pK_2 = 7.1$) and NH_3 as shown in reaction 3

$$\underset{\text{(pH 7.0)}}{NH_3 + CaHx} \longrightarrow \underset{\text{(pH 8 to 9)}}{CaNH_4x \text{ (nonvolatile)}} \qquad 2$$

$$\underset{\text{(pH 7.1)}}{2NH_3 + Ca(H_2PO_4)_2.2CaHPO_4} \longrightarrow \underset{\substack{\text{(pH 8 to 9)} \\ \text{(nonvolatile)}}}{Ca(NH_4HPO_4)_2 + 2CaHPO_4} \qquad 3$$

Even very calcareous soils can retain NH_3 by direct exchange. A Florida marl[5] with a $CaCO_3$ content of over 90% was found to contain 5 pounds of ammonia nitrogen per acre and no ammonia toxicity to

[5]Unpublished studies of E. Truog and O. J. Attoe, 1944.

tomatoes occurred where 5 to 6% of organic matter (high in exchange) were present in the marl, whereas toxicity occurred where less than 3% of organic matter was present. This showed ammonia sorption was taking place in this highly calcareous-alkaline marl.

(c) NH_3 can also dissolve in the soil moisture, thereby decreasing greatly its rate of diffusion into the atmosphere. This rate is governed by its concentration and the temperature. This in part explains the increased sorption of NH_3 by moist beach sand (Fig. 2).

(d) NH_3 can also be sorbed physically on the surface of soil particles, particularly the finer fraction of the soil. Pinner (10) in his investigation of NH_3 gas sorption by soil concluded that the sorption of ammonia gas varies considerably on account of the complex nature of the soil. It is therefore difficult to formulate a sorption theory applicable to all kinds of soil. However, he concluded (10) that the theory of Freundlich according to which sorption is a condensation process occuring at the surface of soil particles is the most probable.

The remarkable rapidity and effectiveness of soil in sorbing NH_3 are brought out by a consideration of the gas volume relationships. The actual rates of NH_3 application used, expressed as parts per 2 million, was made 5 times the pounds per acre rate to allow for the extra concentration in the NH_3 injector path in the field (assumed spacing at 15-inch intervals). Calculations show that for 60 pounds of N per acre, the gas applied amounts to 4.8 liters of gas per lineal foot traversed by the injector in the field, or about 1 liter per square foot on the average (broadcast basis without the concentration factor). In the experimental apparatus, involving about 750 ml. of soil, the gas applied at 60 pounds of N per acre was 246 ml. This is about one-third the volume of the soil and equal to or greater than the air-space porosity of the soil. With a 600-pound per acre application of N, the gas released was 3.3 times the volume of soil, or 13 times the air-space porosity of the soil. It is recalled that 49/50 of the gas present was removed in each of 12 2-minute evacuation cycles. Also, that conservation of NH_3 at the 600-pound rate was almost complete even in the coarse aggregates. Thus, the almost instantaneous sorption of this volume of gas by the soil with zero losses recorded illustrates the truly remarkable nature of the sorption rate and sorption capacity of soil for gaseous NH_3. It is therefore apparent that gaseous losses from the soil is not an important factor in the use of anhydrous ammonia as a fertilizer.

SUMMARY

The purpose of this investigation was to determine the immediate sorption of anhydrous ammonia by soil against diffusion into the atmosphere as influenced by the soil texture, moisture content, pH value, and tilth, when anhydrous ammonia is applied at agriculturally practicable rates directly to the soil.

A technique for this determination was devised and evaluated. Approximately 1 kgm of soil was placed in an 800-ml beaker with an injecting tube inserted at the center of the soil to various depths. The beaker and soil were placed within a vacuum desiccator. Anhydrous

ammonia was introduced into the injection tube by a special pipette and then the tube stoppered. The desiccator was subjected to evacuation and aspiration cyclicly for 30 minutes (12 cycles), the air being drawn through a standard acid trap which collected the escaping NH_3. The excess of acid was back-titrated by standard NaOH solution.

The results may be summarized as follows:

1. If the soil is of intermediate texture, moisture content, and pH value, an application of 60 pounds of nitrogen per acre in form of anhydrous ammonia at a depth of 1 to 2 inches is practically all sorbed instantly, and there is little loss by gaseous diffusion.

2. The coarse-textured soil, Plainfield sand, retained the gaseous ammonia with approximately as great efficacy as did the heavier textured soil, Crosby silt loam. This was especially true in the moist, neutral condition. Even in the air-dry condition, this sandy soil contains enough clay (about 6%) to provide adequate sorption capacity for the NH_3.

3. The moisture content, air-dry soil as compared to field-moist, exerts only a slight effect on sorption efficacy, and this factor can probably be neglected in field practice.

4. Increase in pH value, effected by the presence of free $CaCO_3$ or the alkalinity due to Na_2CO_3, did not prevent satisfactory conservation (95 to 100% conserved) of gaseous ammonia by the field-moist soils when the placement was at 2 to 4 inches depth. This was true even at the excessive rate of 600 pounds of N per acre.

5. Coarse tilth did not interfere greatly with the efficacy of sorption in comparisons of aggregates of 2 to 6 mm diameter to fine soil (less than 2 mm).

6. The actual volume of NH_3 gas involved is approximately 4.8 liters per lineal foot if traversed by injectors at 15 inch spacing at an application rate of 60 pounds of N per acre. The soil, even when air-dry, sorbed almost instantly over 3 times its own bulk volume (13 times its air-space porosity volume) of NH_3, thus illustrating the tremendous power of the soil for preventing loss of gaseous NH_3 applied as fertilizer. It is therefore apparent that gaseous loss of NH_3 from the soil is not an important factor in the use of anhydrous ammonia as a fertilizer.

LITERATURE CITED

1. ANONYMOUS. Nitrogation with shell NH_3 on irrigated farms. Shell Chem. Co., San Francisco, Calif. 1942.
2. ————. The utilization of government synthetic ammonia plants for fertilizer production. U.S.D.A. Mimeo. by a working group of the inter-bureau committee on post-war programs. 1944.
3. ANDREWS, W. B., EDWARDS, F. E., and HAMMONS, J. G. Ammonia as a source of nitrogen. Miss. Agr. Exp. Sta. Bul. (Prelim.) May 1947.
4. CHAPMAN, H. D. Effect of nitrogenous fertilizers, organic matter, sulfur, and colloidal silica on the availability of phosphorus in calcareous soils. Jour. Amer. Soc. Agron. 28:135–145. 1936.
5. FORDE, H. I., and PROEBSTING, E. L. Utilization of ammonia supplied to peaches and prunes at different seasons. Hilgardia, 16:411–425. 1945.
6. JOHNSTONE, J. Elements of Agricultural Chemistry. C. M .Saxton. 1853. (Page 223.)

7. LEAVITT, F. H. Process for soil fertilization. Patented June 9, 1942. U. S. Patent Office, Patent Application serial No. 286, 569, July 26, 1939.
8. MACINTIRE, W. H., WINTERBERG, S. H., DUNHAM, H. W., and CLEMENTS, L. B. Response of sudan grass to ammonium hydroxide in pot cultures. Soil Sci. Soc. Amer. Proc., 8:205–210. 1944.
9. MILLER, E. C. Plant Physiology. New York: McGraw-Hill Book Co. Ed. 2. 1938. (pages 644–648.)
10. PINNER, L. Fresh researches on the absorption of ammonia by the soil. Kuhn-Archiv, 6: Part 1, 153–238. 1915. (Abstracted in Int. Inst. Agr.) Monthly Bulletin of Agricultural Intelligence and Plant diseases, Year VI: Part 1, 1304–1305. 1915.
11. ROSENSTEIN, L. Increase yields obtained from shell agricultural ammonia (NH_3) in irrigated agriculture. Shell Chem. Co. Bul. No. 1. 1936.
12. TIEDJENS, V. A., and ROBBINS, W. R. The use of ammonia and nitrate nitrogen by certain crop plants. N. J. Agr. Exp. Sta. Bul. 526. 1931.
13. WAYNICK, D. D. Anhydrous ammonia as fertilizer. Calif. Citrograph, 19, No. 11. 1934.

The Effect of Rate of Nitrogen Application Upon the Weight and Nitrogen Content of the Roots of Sudan Grass[1]

L. A. Pinck and F. E. Allison[2]

The importance of the roots of various cultivated crops in the maintenance of soil organic matter has received increasing emphasis in recent years. In our own work[3] it was found that, under greenhouse conditions, where five successive crops (four of Sudan grass and one of wheat) were grown on the same soil, its carbon content was increased about 30% over the control by the use of an abundant supply of nitrogen. In these experiments the root residues were the only source of added carbon. Usually any change in growth conditions or treatment that increases the yield of the above-ground portion of the crop will also increase the quantity of roots produced but not necessarily proportionately. There is much information now available, which need not be reviewed here, that gives the average percentages of the total dry weights of various plants that are present in the roots. It is also known in a general way that the top-root ratio of a given crop may change with the age of the plants, rate of nitrogen application, abundance of phosphorus, length of day, degree of soil aeration, and other factors. There is, however, only a limited amount of information concerning the effect of these variables upon the root weights and nitrogen contents of any given crop. In connection with work already reported in part and other work in progress, it was desirable to have quantitative information upon the proportion of the total dry weight and protein of Sudan grass that is present in the roots harvested at various stages of maturity. An experiment designed to obtain these data is reported here.

EXPERIMENTAL

The experiment was conducted in the greenhouse using 2-gallon glazed pots that held 20 pounds of Evesboro loamy sand. This soil was limed to a pH of approximately 6.5 and 2 weeks later a basal application of 1,000 pounds per acre of a 0–15–6 fertilizer was made to all pots which were then planted to Sudan grass. This was done in order to remove most of the available soil nitrogen prior to starting the main experiment. Both the tops and roots of the grass were removed when the crop was about 2 feet high. The soil from all of the pots was then mixed together and repotted. A second application of 1,000 pounds of the 0–15–6 fertilizer was added to all pots, together with an adequate supply of boron, copper, zinc, manganese, molybdenum, and magnesium. In addition, nitrogen in the form of urea was added to the various pots to furnish from 0 to 200 pounds of nitrogen per acre, as shown in Table 1.

All treatments were in duplicate and provided for harvests at three stages of maturity. The pots were arranged in randomized blocks and were rotated within

[1]Contribution from the Division of Soils, Fertilizers, and Irrigation, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication March 28, 1947.

[2]Associate Chemist and Senior Chemist, respectively.

[3]Pinck, L. A., Allison, F. E., and Gaddy, V. L. Greenhouse experiments on the effects of green manures upon nitrogen recovery and soil carbon content. Soil Sci. Soc. Proc., 10: 230–234. 1946.

the blocks at frequent intervals. The Sudan grass was planted on May 23, 1946. The three dates of harvest were 25, 46, and 75 days after planting. At the last harvest the grass was fully mature. Since the roots could not be freed of all soil particles by washing, they were analyzed for ash and a correction made for the soil present. The dry weights and total nitrogen contents of the tops and also of the roots, together with the calculated percentages of the weights and nitrogen found in the roots, are given in Table 1. Analysis of variance were made of the data, showing the effect of rate of nitrogen application and stage of maturity upon the percentage of dry matter and nitrogen in the roots.

TABLE 1.—*The dry weights and nitrogen contents of the tops and roots of Sudan grass grown to different stages of maturity with varying rates of application of nitrogen.*

Pounds of urea nitrogen added per acre	Average dry weights			Average total nitrogen*		
	Tops, grams per pot	Roots, grams per pot	% in roots†	Tops, mgms per pot	Roots, mgms per pot	% in roots‡
			Young			
0	3.4	2.7	44.2	45.5	40.0	46.8
20	4.0	2.0	33.1	84.3	36.2	30.1
40	4.3	2.1	33.5	120.0	45.7	27.6
80	4.2	2.2	34.2	143.1	51.5	26.5
120	5.1	2.0	29.7	181.2	54.1	23.0
160	5.4	2.5	31.3	203.3	70.2	25.7
200	5.5	2.4	30.5	218.0	74.5	25.5
			Intermediate			
0	8.9	5.8	39.6	58.4	38.1	39.5
20	13.8	7.9	36.3	95.8	54.6	36.3
40	15.9	8.6	35.2	118.2	63.6	35.0
80	19.6	9.4	32.4	174.1	76.4	30.5
120	21.7	10.2	32.0	262.4	139.3	34.7
160	23.8	10.0	33.8	326.1	145.5	30.9
200	25.4	10.0	28.2	401.0	143.2	26.3
			Mature			
0	19.4	9.9	33.8	76.6	65.4	46.1
20	33.6	19.9	37.1	160.0	139.2	46.5
40	34.1	20.5	37.5	164.3	131.7	44.5
80	39.4	17.4	30.6	222.8	115.5	34.1
120	50.6	28.2	35.7	358.5	207.2	36.6
160	58.0	24.6	29.8	337.6	157.7	31.8
200	62.2	28.0	31.0	465.5	239.2	33.9

*The nitrogen analyses were made by Mrs. Luann Sterling.
†Least significant difference at the 19:1 level = 4.5.
‡Least significant difference at the 19:1 level = 5.9.

DISCUSSION OF RESULTS

If the results be considered as a whole, the stage of maturity of the plants when harvested did not significantly affect the percentage of the total dry matter in the roots. In other words, as the plants grew older both the roots and tops increased in weight at the same rate, approximately one-third of the dry weight being in the roots. This was a somewhat unexpected result. The analyses of the nitrogen

data, however, show a very different result. In this case there was a very highly significant effect of age of plants; as they grew older a considerably higher proportion of the total plant nitrogen was found in the roots. These percentages for the young, intermediate, and mature plants were 27.7, 31.5 and 37.2, respectively. Since the proportion of weight of roots to tops did not change with age, it is obvious that the percentage of nitrogen in the tops decreased much more rapidly than it did in the roots as the plants grew older.

The addition of increasing amounts of nitrogen produced highly significant decreases in the proportion of both the dry matter and nitrogen in the roots of Sudan grass. The stimulating effect of nitrogen on top growth without a corresponding increase in root growth manifested itself both in the dry weights and in the nitrogen contents of the plant parts. Although the nitrogen effect was similar in both cases, it was somewhat more striking on the protein content than on the dry weights. In going from no nitrogen to 200 pounds per acre, the percentage of dry matter in the roots decreased from 39 to 30; the corresponding figures for nitrogen content being 44 and 29%. This tendency of nitrogen to increase the top growth more than the root growth has been observed repeatedly by many workers using various crops. With abundant nitrogen present the photosynthesized carbohydrates are used more largely in the tops where produced. There is also less need for the plant to send out more roots in search of nutrients.

The age × nitrogen interaction with respect to both the proportion of roots and their nitrogen contents was significant. The main factor seems to be that a smaller amount of nitrogen is required to depress the proportion of root growth and nitrogen content of young plants than of older ones. It is rather surprising that this was not even more in evidence.

In these experiments where urea was added in increasing amounts, the recovery of nitrogen by the Sudan grass grown to maturity averaged only about two-thirds of that added, even though both the the tops and roots were harvested. Furthermore, the low recoveries were not limited to the higher rates of additions. Doubtless much of the unrecovered nitrogen was retained by the soil in a form not readily utilized by the higher plant, but there also exists the possibility that some loss of gaseous nitrogen may have occurred.

SUMMARY

A greenhouse experiment designed to determine the effect of varying rates of nitrogen additions upon the percentage of roots and of total nitrogen in the roots of Sudan grass grown to different stages of maturity gave the following results:

1. The proportion of the total weight of the plants found in the roots was approximately one-third regardless of the stage of maturity at the time of harvest.

2. As the plants increased in maturity a considerably greater percentage of the total plant nitrogen was found in the roots. These values were 28, 32, and 37% for young, intermediate, and mature Sudan grass, respectively.

3. Nitrogen additions caused a highly significant decrease in the proportions of both the total dry weight and the total nitrogen found in the roots. This effect was slightly less pronounced for the weights than for the nitrogen contents.

4. The response of the plant roots at different stages of growth to increasing amounts of nitrogen were similar but not identical. Small amounts of nitrogen had slighlty more effect in decreasing the proportion of dry matter and of nitrogen in the roots of young than of old plants.

5. Only about two-thirds of the added urea nitrogen was recovered in the tops and roots even though the plants were grown to maturity.

Note

IRON DEFICIENCY OF CRIMSON CLOVER ON A CALCAREOUS SOIL AND METHOD OF DIAGNOSIS[1]

THE Blackland Prairie of Albama has undergone in the last 30 years a remarkable conversion from cotton farming to a grassland agriculture. In the process of this change, the introduction of several legumes new to the region have presented some important soil fertility problems, particularly on the calcareous soils. It was found early in the search for grazing crops that white clover, *Trifolium repens*, was well adapted to the fine-textured lime soils. This plant rapidly became the key legume in the improved permanent pastures of the area.

In a search for a winter legume for grazing, crimson clover, *Trifolium incarnatum*, was seeded on Houston clay, a calcareous Rendzina soil developed from Selma chalk, on the Black Belt Substation, Marion Junction, Ala., in the fall of 1945. The clover, which was fertilized with approximately 400 pounds per acre of 0–14–10, came up

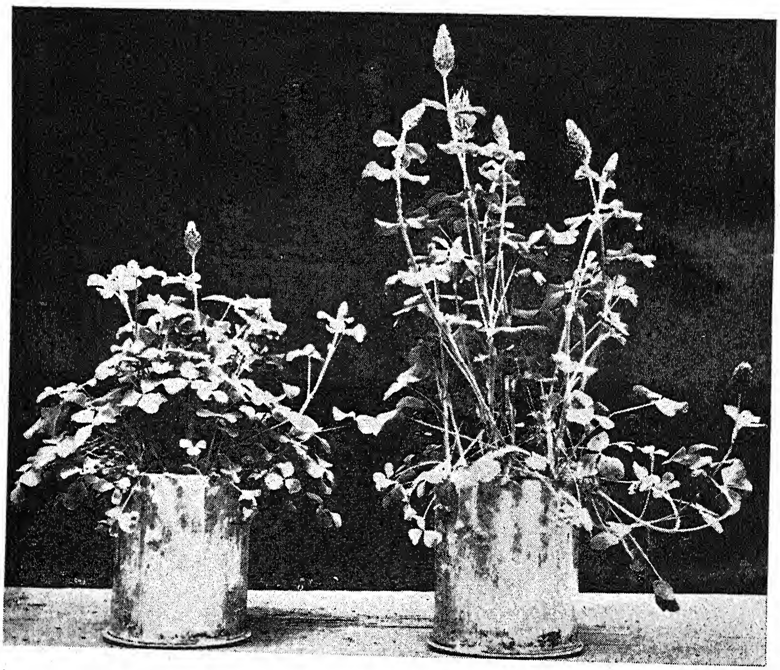

FIG. 1.—Technique used in studying plant nutrient deficiencies of crimson clover. The soil and plants are taken from the field intact while the plants are small and treated with various nutrient solutions. Left, received NH_4NO_3; right, sprayed with $FeSO_4.7H_2O$.

[1]Acknowledgment is due E. D. Donnelly and A. R. Carlton, students at the Alabama Polytechnic Institute, who conducted the greenhouse study as a special soils problem.

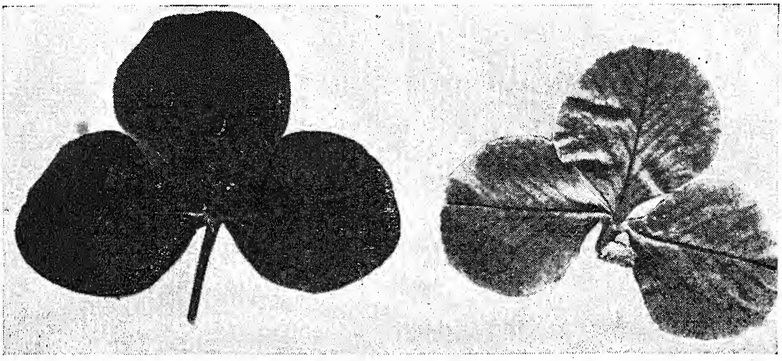

FIG. 2.—Chlorotic and normal crimson clover leaves grown on Houston clay. *Left*, normal leaf from plants sprayed with $FeSO_4.7H_2O$; *right*, chlorotic leaf from untreated plants.

to a good stand but soon developed marked chlorosis. Chandler and Scarseth[2] reported that iron starvation limited the growth of lespedeza, crotalaria, peanuts, and sweet potatoes on these calcareous clays, but the author found no report of crimson clover failure due to lime-induced chlorosis under field conditions.

In order to diagnose the deficiency, specimens of the clover and soil were brought to the greenhouse and various combinations of N, B, Cu, Fe, Mg, Mn, and Mo were applied. The soil and plants were taken up intact in No. 2 tin cans, which had been shellacked on the inside. The cans with tops and bottoms removed were forced into the soil in the field when the clover plants were small. The soil column was cut off with a large spatula and the bottoms spot soldered onto the cans with very little disturbance of the soil or plant roots. This technique was used to obviate the partial sterilization effects of air drying and to maintain the physical condition of the soil as found under field conditions. Fig. 1 shows the clover plants in the cans in the greenhouse at the completion of the test. Because of the variation in soil and plant population, the treatments were applied in quadruplicate. No attempt was made to determine yields, since it was easy to determine from the appearance of the foliage which treatment corrected the lime-induced chlorosis.

The application of ferrous sulfate as a spray (0.1% Fe) every 3 to 4 days produced normal green leaves, whereas none of the other treatments corrected the chlorotic condition of the foliage (Fig. 2). The addition of ammonium nitrate intensified the chlorophyll deficiency and delayed maturity of the plants (Fig. 1).

The addition of ferrous sulfate to the soil failed to correct the iron deficiency symptoms, indicating precipitation of the iron in an unavailable form in the calcareous soil.—H. T. ROGERS, *Alabama Agricultural Experiment Station, Auburn, Ala.*

[2]CHANDLER, W. V., and SCARSETH, GEORGE D. Iron starvation as affected by overphosphating and sulfur treatment on Houston and Sumter clay soils. Jour. Amer. Soc. Agron., 33:93–104. 1941.

Book Review

SEQUENTIAL ANALYSIS

By Abraham Wald, New York: John Wiley and Sons, Inc. XII+212 pages, illus. 1947. $4.

THE author says "sequential analysis is a method of statistical inference whose characteristic feature is that the number of observations required by the procedure is not determined in advance of the experiment. The decision to terminate the experiment depends, at each stage, on the results of the observations previously made." This entirely new type of inference, which represents a major advance in the fundamental theory of statistics, has been developed largely by the author during the past four years, although J. Neyman and E. S. Pearson published some phases of the problem in 1938.

This book by Doctor Wald presents the mathematical theory of only one phase of this new statistical technique, *viz.*, The Sequential Probability Ratio Test which was developed by him in 1943. In fact, the entire book represents his own contributions with few exceptions and in all such instances credit is given the investigators who developed special techniques.

As the reviewer studied this book, he was impressed by four facts: (1) The volume of mathematical theory originated by the author, (2) the varied practical uses for this theory, (3) the magnitude and value of the task, and (4) the painstaking effort made to present the material in a logical, thorough, and lucid manner. Doctor Wald is to be congratulated for this contribution which is claimed to be "the first book-length treatment" of "this important new statistical technique." The book is well printed and attractively bound, thus maintaining the high standards of the publishers.

This is not a handbook of methods that can be applied by the average biologist, since no complete numerial example of application is given, but deals entirely with mathematical theory. To be sure, the author states the application to certain problems but does not show the necessary arithmetic needed by many to handle these same problems. The reviewer believes that the work will prove difficult reading for many biologists who use statistical inference when interpreting their data even though it is stated in the preface that "an effort has been made to keep the exposition on a level that will make most of the book, with the exception of the Appendix, understandable to readers whose mathematical background does not go beyond college algebra and a first course in calculus." To those who are thoroughly prepared, the book will be very welcome. There are some workers, with a fair background, to whom mathematical theory is difficult to apply. Such persons will derive much help in understanding Doctor Wald's book if they use it in conjunction with "Sequential Analysis of Statistical Data: Applications." prepared by the Statistical Research Group, Columbia University, of which Doctor Wald was a member, published by Columbia University Press in 1945. Also, a very good paper which illustrates the use of certain phases of the method is "An Application of Sequential Sampling to Testing Stu-

dents" by Dudley J. Cowden, Jour. Amer. Statistical Assoc., 41:547–556, 1946.

The applications of sequential analysis proved of such value during the war for rapid, efficient inspection techniques of war material as well as for the study of various military and naval problems that it was kept secret for a certain period. The fact that much of this theory is applicable to research problems such as are common to biological workers makes it advisable that investigators study this theory and learn to adapt it to their studies. For such this book is a foundation. It is hoped, however, that before long accurate, concise, authoritative manuals showing numerous applications of sequential analysis will be published.

The treatise is divided into three parts with the addition of an appendix and an index. The part and chapter headings are as follows:

Part I, General Theory.—Elements of the Current Theory of Testing Statistical Hypotheses; Sequential Test of a Statistical Hypothesis: General Discussion, the Sequential Probability Ratio Test for Testing a Simple Hypothesis H_0 Against a Single Alternative H_1; Outline of a Theory of Sequential Tests of Simple and Composite Hypotheses Against a Set of Alternatives.

Part II, Application of the General Theory to Special Cases.—Testing the Mean of a Binomial Distribution (acceptance inspection of a lot where each unit is classified into one of two categories); Testing the Difference Between the Mean of Two Binomial Distributions (double dichotomies); Testing that the Mean of a Normal Distribution with a Known Standard Deviation Falls Short of a Given Value; Testing that the Standard Deviation of a Normal Distribution Does not Exceed a Given Value; Testing that the Mean of a Normal Distribution with Known Variance is Equal to a Specified Value.

Part III, The Problem of Multi-valued Decisions and Estimation.—The Choice of a Hypothesis from a Set of Mutually Exclusive Hypotheses (multi-valued decisions); The Problem of Sequential Estimation.

The following are the titles of the subjects discussed in the Appendix: Proof that the Probability is 1 that the Sequential Probability will Terminate; Upper and Lower Limits for the OC Function of a Sequential Test; Upper and Lower Limits for the ASN Function of a Sequential Probability Ratio Test; Derivation of exact Formulas for the OC and ASN Functions when z can Take only a Finite Number of Integral Multiples of a Constant; The Characteristic Function and Higher Moments of n; Approximate Distribution of n when z is Normally Distributed; Efficiency of the Sequential Probability Ratio Test; Determination of an Optimum Weight Function $w(\Theta)$ in some Special Cases of Testing Simple Hypotheses with no Restrictions on the Possible Alternative Values of the Parameters; Determination of Optimum Weight Functions $w_a(\Theta)$ and $w_r(\Theta)$ in Some Special Cases of Testing Composite Hypotheses.—F. Z. HARTZELL.

AGRONOMIC AFFAIRS

CHANGE OF DATE OF ANNUAL MEETING—NOVEMBER 17 TO 20, INCLUSIVE

DUE to a conflict in dates which has arisen with the Netherland Plaza Hotel in Cincinnati, the Executive Committee has advanced the date for the meetings of the American Society of Agronomy and the Soil Science Society by one day. The meetings will be held on Tuesday, Wednesday, and Thursday, November 18 to 20, inclusive, with the special fertilizer session to be held on Monday, November 17.

This change in date will bring the general program, business session, and banquet on Wednesday instead of Thursday, as in the past. It is hoped, too, that starting the meetings on Monday will prove advantageous to those who have teaching responsibilities in that they could utilize Sunday for traveling.

WANTED: A NAME

THE special committee headed by Doctor K. S. Quisenberry and charged with the development of the proposed popular journal on applied agronomy to be published by the Society finds a difference of opinion among the members of the Society as to whether the present title of the new magazine, "Agronomic Progress", is the best possible one. Few persons, however, have had anything different to offer in the way of a name for the new publication.

The committee will welcome suggestions along this line and will weigh all ideas carefully. The name should be brief, descriptive, and should avoid the use of the word "journal". Address all communications on this subject to Doctor Quisenberry, Plant Industry Station, Beltsville, Md.

MEETING OF NORTHEASTERN BRANCH OF SOCIETY

THE University of Vermont and MacDonald College, Province of Quebec, were joint hosts to the Northeastern Branch of the American Society of Agronomy, June 23 to 25. About 150 agronomists attended the summer meeting. Officers elected for the coming year were: President, Paul Miller, University of Vermont; Vice President, Claude Phillips, University of Delaware; and Secretary-Treasurer, Samuel R. Aldrich, Cornell University.

American Society of Agronomy JOURNAL

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Barley Culture in Japan[1]

WARREN H. LEONARD[2]

BARLEY is one of the most important crops grown in Japan, being produced both for food and forage. During the period from 1936 to 1940, the cultivated area devoted to the crop was about 14% of the arable land area. When the covered and naked types are included together, barley ranks second in acreage among all cultivated crops, being exceeded only by rice which occupies 53% of the cultivated area. About 60% of the crop is naked barley[3] and 40% covered. The comparative acreage and production of rice, wheat, and barley in Japan and in the United States for the periods from 1936 to 1940 and from 1941 to 1945 are given in Table 1.

The acreage and production of barley in Japan were gradually increased after the Meiji Restoration in 1868 to meet the food demands of the growing population but declined in acreage after World War I (1914–18) because of less emphasis on barley for food. Some of the decrease can be attributed to the increased production of wheat that took place after 1933 as a result of the 5-year program inaugurated by the Japanese Government to make the country self-sufficient in wheat. There was a slight increase in barley production from 1937 to 1942, but thereafter a decrease largely because of the fertilizer and labor shortages brought on by World War II (1941–45).

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[1]Authorized by the Director of the Colorado Agricultural Experiment Station for publication as scientific journal series article No. 246. Received for publication March 31, 1947.

[2]Professor of Agronomy, Colorado A. and M. College, Ft. Collins, Colo. Formerly, Major, CAC, US Army, and Chief, Agriculture Division, Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers, Tokyo, Japan, from October 2, 1945, to August 20, 1946. Acknowledgment is made to Dr. H. Terao, retired Director, Imperial Agricultural Experiment Station, Nishigahara, Tokyo, Japan, for valuable aid in the collection of material for the preparation of this paper. Helpful criticisms of the manuscript were made by Dr. S. C. Salmon, Principal Agronomist in Charge of Wheat Investigations, and by Dr. G. A. Wiebe, Principal Agronomist in Charge of Barley Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. Valuable suggestions were also received from Dr. Carl L. W. Swanson, Soils Department, Connecticut Agricultural Experiment Station, New Haven, Conn. The writer wishes to express his gratitude to Lt. Col. H. G. Schenck, Chief of the Natural Resources Section, GHQ, SCAP, for his encouragement on the preparation of scientific papers on Japan.

[3]Naked barley threshes free of the glumes as in common wheat.

TABLE 1.—*Comparative acreage and production of rice, wheat, and barley in Japan and in the United States, 1936–40 and 1941–45.**

Crop	Japan proper			United States		
	Total acreage, 1,000 acres	Total production, 1,000 bus.	Yield per acre, bus.	Total acreage, 1,000 acres	Total production, 1,000 bus.	Yield per acre, bus.
	Annual Average, 1936–40					
Rice (rough)†....	7,851	587,243	74.8	1,054	52,849	50.2
Wheat‡.........	1,826	54,401	29.8	57,194	789,133	13.8
Barley (naked)§	1,029	30,622	29.8	Trace	Trace	—
Barley (covered)§	845	35,671	42.2	10,879	239,207	21.8
	Annual Average, 1941–45					
Rice (rough).....	7,576	510,355	67.4	1,418	63,820	44.9
Wheat..........	1,992	46,506	23.3	55,984	989,039	17.7
Barley (naked)...	1,202	31,113	25.9	Trace	Trace	—
Barley (covered).	965	31,346	32.5	13,732	333,332	24.3

*Statistics from Japan computed from data furnished by the Ministry of Agriculture and Forestry, Imperial Japanese Government, Tokyo, 1946.

†Japanese data are ordinarily computed in terms of brown rice, but they have been converted to a rough rice basis for comparability with U. S. data. The Japanese data on the basis of brown rice are 337,206,000 bushels production, or 43.0 bushels per acre average for period 1936–40; and 293,090,000 bushels production, or 38.7 bushels per acre for 1941–45. Conversion factors: 1 bushel brown rice weighs 63 pounds and 1 bushel rough rice 45 pounds. It requires 1.74129 bushels of rough rice to make 1 bushel of brown rice.

‡One bushel wheat weighs 60 pounds.

§One bushel covered barley weighs 48 pounds and one bushel naked barley 60 pounds.

GEOGRAPHICAL DISTRIBUTION

The general climatic conditions in Japan influence the geographical distribution of barley. Differences in temperature are marked throughout Japan. January temperatures range from about 10° to 15°F in northern Hokkaido to 40°F on the lowlands of central Japan and 45°F in the extreme south of Kyushu. The temperature range in July is from 65° to 68°F in northern Hokkaido and from 77° to 80° in southern Kyushu. The growing season for crops ranges from 120 to 130 days in central Hokkaido to 250 days or more in southwestern Japan. The average annual precipitation ranges from about 40 inches in Hokkaido to 120 inches in areas of central and southwestern Japan. Precipitation is heaviest in the summer months and lightest in the winter months. Winter precipitation in the form of snow is especially heavy in those regions which face the Sea of Japan. The snow ranges in depth from 3 to 10 feet and remains on the ground from 80 to 100 days over much of that area.

The geographical distribution of the barley crop in Japan is shown in Fig. 1. Except for small areas along the Japan Sea, barley is cultivated primarily in the Kanto District and southward. Among the factors that influence this distribution are the winter temperature, precipitation, snowfall, and drainage of the land. Barley also competes for land with wheat and winter vegetables. With few exceptions, the barley crop is of spring type but is fall-seeded. Naked barley predomi-

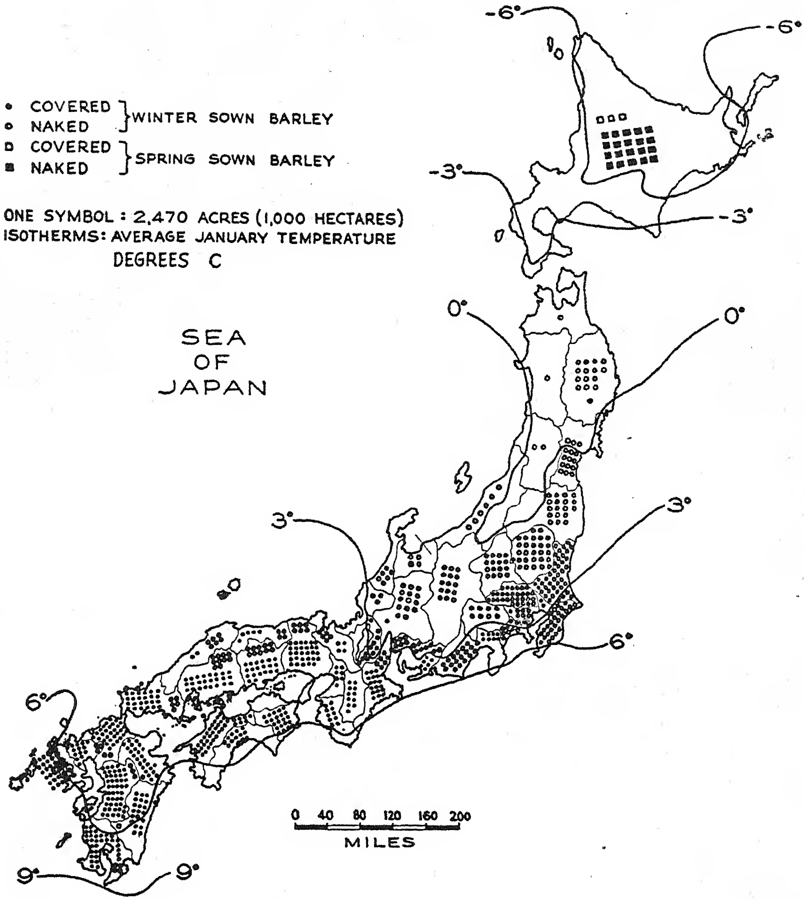

FIG. 1.—Geographical distribution of barley types in Japan.

nates in southwestern Japan mostly in areas with an average January temperature of 3°C (37.4°F) or higher, while covered barley is grown most widely in central and northern Japan where the winter temperatures are lower. The agricultural districts are shown in Fig. 2.

In the warmer districts of southwestern Japan both wheat and barley are fall-planted not only on upland fields but also on paddy fields dried out after the rice crop has been harvested. Consequently, the planted acreage of those crops depends on the ability to drain the rice fields. Both summer and winter barley crops are cultivated successfully each year in the warmer areas.

In the northeastern (Tohoku) district of Honshu, and in Hokkaido, barley is grown as a spring crop in the colder areas but as a winter crop where it can ordinarily survive the winter climate. In both districts the winter barley crops sometimes fail because of injury by low

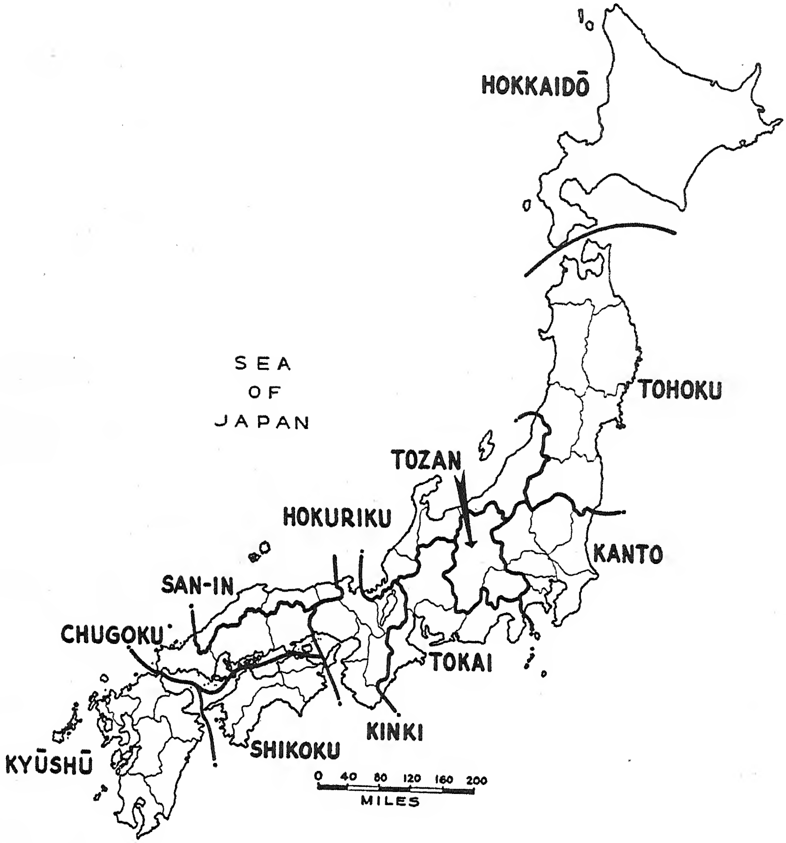

FIG. 2.—Agricultural districts of Japan.

temperatures, or by heavy snow cover. In these northern districts the cultivation of barley is not so common as in the warmer districts.

In the north-central (Hokuriku) district along the Japan Sea, as well as south of this area, the winter temperature is high enough for successful barley culture (Fig. 1). However, the acreage in this area is small because upland fields are scarce, the paddy fields are too wet, and snow covers the land for so long (80 to 120 days) that fall-seeded barley is often killed out or greatly reduced in stand. In order to plant barley as a fall crop in advance of the rainy season in October in this district, the preceding summer crop must be harvested early. This condition hinders the wide distribution of barley culture, as well as that of other crops, in the Hokuriku district.

Several factors influence the distribution of barley in local areas, among them being soil conditions and farm practices. The distribution of the barley crop depends partly on how well it fits into the rice-barley sequence. The crop is largely grown in the districts where

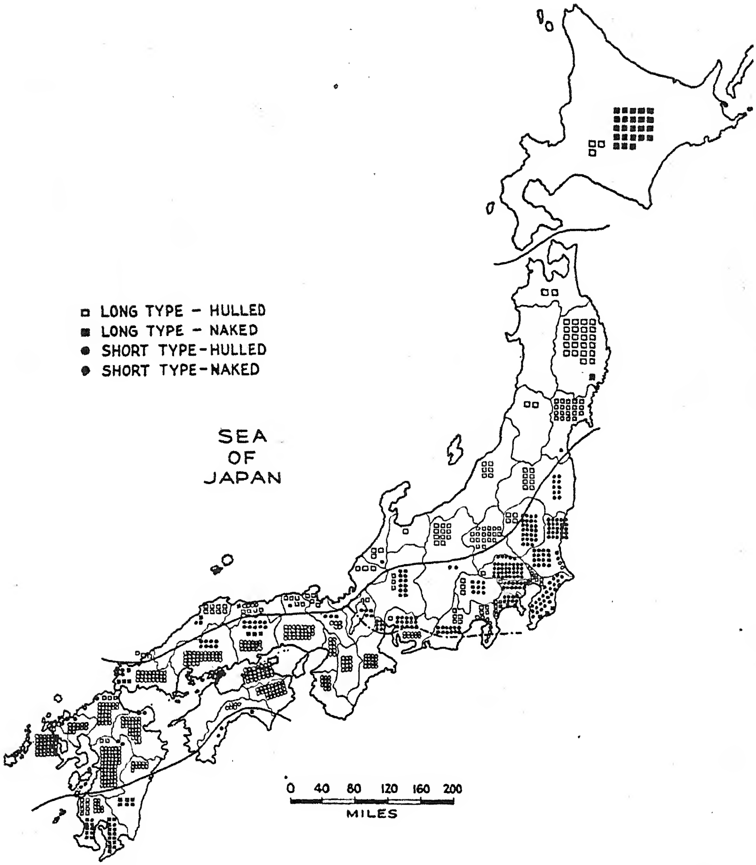

FIG. 3.—Geographical distribution of short- and long-stemmed barley types in Japan.

the cultivated area per farm is small, i.e., 2.5 acres or less in size, as in the southern part of Japan. This is true particularly in Ehime, Tokushima, Kagawa, Kochi, Hiroshima, and Nagasaki prefectures. Barley is grown extensively in Hyogo, Okayama, Kumamoto, Miyazaki, and Iwate prefectures as feed for livestock.

REGIONAL TYPES AND VARIETIES

Almost all barley grown in Japan is common six-row barley, *Hordeum vulgare*, but there are a few varieties each of *H. intermedium* and *H. distichon*. Most of the crop is spring barley seeded in the fall. A typical feature of Japanese awned barleys is the short awns found in most commercially grown varieties.

Regional types based on plant height.—Japanese barley varieties show a wide variation in culm length, the shortest being about 20

inches (50 cm), while the longest are about 43 inches (110 cm). Takahashi[4] classified the barley varieties grown in Japan into two groups, namely, tall and short plant types. These types were found to be distributed in distinct geographic areas (Fig. 3). Furthermore, the culm length was found to be correlated with coleoptile length, the division between the long and short types being approximately 1.3 inches (34 mm).

The tall and short types include both covered and naked varieties. The tall varieties are generally grown on the poorer soils in the colder regions north of the Kanto Plain. The naked tall type is grown in Hokkaido, the most northern part of Japan, where it is spring-sown. The covered tall type of winter habit is grown in the Tohoku, Hokuriku, and San-in districts. The tall type also appears in the most southern part of Kyushu.

The short-type varieties are found almost entirely on highly fertile soils in the warmer regions of the middle and southern part of Japan proper. The relative position of the covered and naked varieties is almost reversed in this region. The covered varieties are grown in the north in the Kanto and Tokai districts, while the naked ones are in the south, particularly in the Kinki, Chugoku, Shikoku, and Kyushu (northern part) districts.

Agricultural varieties.—There are many cultivated varieties of barley in Japan because of the diverse climatic conditions, soil variations, and the different cultural methods followed in the various districts or by individual farmers. A total of 114 covered and 81 naked varieties are recommended by the prefectural agricultural officials. There are probably five or six times as many varieties when all the local ones are included. From 70 to 80% of the barley acreage is planted to varieties recommended by the prefectural governments.

In the colder region of northeastern or north central Japan the locally grown varieties are characterized by late ripening, long culms, long heads, and both snow and cold resistance. Because of the comparatively cool temperatures, similar varieties are grown in the mountainous areas of the warmer districts southwest of the Kanto Plain near Tokyo.

In the warmer areas of southwestern Japan the varieties grown are of comparatively early maturity, short culms, and a large number of culms per plant. The early spring temperature is comparatively high in the warmer districts, being accompanied by abundant precipitation. Varieties adapted to such conditions are resistant to yellow rust, *Puccinia glumarum*, red rust, *P. graminis*, and scab, *Gibberella saubinettii*. They also have the characteristic of prolonged dormancy from germination on the head or spike under high rainfall conditions during the harvest season. The varieties grown in the warmer region tend to be low in protein and high in starch as compared with those grown in the colder districts.

Some of the most widely grown varieties of covered barley are listed in Table 2.

[4]TAKAHASHI, R. Studies on the classification and the geographic distribution of the Japanese barley varieties. I. Significance of the bimodal curve of the coleoptile length. Ber. Ohara Inst. fur Landw. Forsch., 9: 71–90. 1942.

TABLE 2.—*Important covered barley varieties grown in Japan, 1942.*

Prefecture	Varieties	Plant type	Culm length, cm	No. of rows	Compactness of head	Awn length, cm	Spring adaptability*	Acres
Iwate	Iwate Manchuria No. 2	Tall	106	6	Lax	11.9	IV	16,309
Miyagi	Miyagi Rokkaku No. 23	Tall	90	6	Medium	8.4	V	7,166
	Miyagi No. 12	Short	81	6	Compact	5.6	V	8,401
Yamagata	Hosomugi	Tall	110	6	Lax	12.0	V	4,201
Fukushima	Sekitori No. 3	Short	75	6	Compact	5.1	V	25,946
Ibaragi	Chikurin							
	Ibaragi No. 2	Short	79	6	Compact	5.2	V	—
Tochigi	Tochigi Sekitori No. 1	Short	79	6	Compact	4.7	V	44,478
	Tochigi Golden Melon No. 1	Tall	109	2	Medium	13.0	IV	11,120
Gumma	Manriki	Short	93	6	Compact	5.6	V	11,861
	Sekitori Den No. 2	Short	75	6	Compact	5.2	V	12,355
Saitama	Sekitori Saitama No. 1	Short	80	6	Compact	4.5	V	64,246
Chiba	Bozu No. 1	Short	94	6	Compact	—	V	12,108
	Sekitori No. 2	Short	98	6	Compact	4.4	V	42,007
Kanagawa	Chikurin	Short	80	6	Compact	5.4	V	12,355
Niigata	Omugi Sin No. 1	Tall	79	6	Lax	11.9	V	3,459
Fukui	Kedaka Rokkaku	Tall	105	6	Medium	10.5	V	3,954
Yamanashi	Suisho Sekitori No. 305	Short	73	6	Compact	4.8	V	5,930
Nagano	Bizen-wase	Tall	100	6	Medium	4.0	V	11,120
Gifu	Tanikaze No. 105	Short	88	6	Compact	5.4	III	18,038
Shizuoka	Kuromugi No. 148	Short	92	6	Medium	5.4	III	10,378
	Shizuoka Shirorokkaku No. 1	Tall	94	6	Compact	9.8	III	12,849
Aichi	Tanikaze No. 2	Short	86	6	Compact	5.7	III	18,532
	Yokuzuna	Short	85	6	Lax	3.8	V	11,367
Mie	Baitori No. 10	Short	89	6	Compact	6.9	III	10,378
Shiga	Shiga Hachikoku No. 5	Short	83	6	Compact	5.0	III	11,367
Kyoto	Wase Golden Melon	Tall	92	2	Compact	10.6	V	1,977
Hyogo	Hachikoku No. 2	Tall	106	6	Medium	4.9	V	5,683
Hiroshima	Baitori No. 11	Short	88	6	Compact	6.3	III	12,602
Yamaguchi	Benkai No. 3	Short	84	6	Compact	4.6	IV	7,660
	Hakata No. 2	Tall	106	2	Compact	14.5	III	1,236
Total								419,083

*Relative degrees of winterness, I to VII. Classes I and II are considered to be spring barleys, classes VI and VII winter barleys, and the others intermediate.

There have been some changes in covered barley varieties grown in Japan since 1942. In Shizuoka Prefecture, Kinai Sekitori No. 2 and Iwate Santoku were being grown widely in 1946. Sekitori Saitama No. 2 occupies a larger acreage on the Kanto Plain than any other variety at the present time.

The most widely grown naked barley varieties in Japan are Kobinkatagi No. 1, Akashinriki, Wasehadaka, Kagawa, Marumi, Yanehadaka, and Shinriki-Hadaka. The recommended varieties for the various agricultural districts are given in Table 3.[5]

TABLE 3.—*Naked barley varieties adapted to various agricultural districts in Japan.*

Agricultural districts	Adapted varieties
Hokkaido	Marumi, Mitsukiko
Tohoku	Tozam-Shirohadaka, Kezen-hadaka
Kanto	Zyoshu-Shirohadaka, Komehadaka, Onihadaka
Tokai	Kobinkatagi, Kagawa, Shirochinko
Kinki	Yanehadaka, Kokubi, Akashinriki, Hakumai, Kairyo, Wasehadaka, Bozu
San-in	Kobinkatagi, Kosaba
Chugoku	Kobinkatagi, Shiroto, Yahazu, Shirochinko
Shikoku	Yanehadaka, Shirochinko, Kobin, Henro, Nihon-ichi, Wasehadaka, Oishi
Kyushu	Takeshita, Shinriki-Hadaka, Shimaoka, Kobinkatagi, Shimabara, Oita-Hadaka, Kobin, Negi, Kamaore, Kairyo-hizahachi

GENERAL CULTURAL PRACTICES

Methods of barley culture in Japan differ greatly from those used in the United States. Fields range in size from a few square yards to about ¼ acre on more level land, except in Hokkaido where barley fields may occasionally be 2.5 acres or more in size. The land is plowed with a one-horse plow or spaded by hand. Seeding, weeding, and harvesting are almost always done by hand labor.

Most of the barley in Japan is grown alternately with another crop in the same season. It follows rice on paddy land, the field often being ridged so that the barley can be planted on top of the ridges. On upland fields, it is a common practice to seed sweet potatoes, soybeans, or upland rice between the standing rows of barley before the grain is harvested.

CULTURAL METHODS ON UPLAND FIELDS

After the previous summer crop has been harvested Japanese farmers ordinarily apply about 450 pounds of lime per acre in preparation for the fall seeding of barley because of the acidity of most Japanese soils.

Seedbed preparation.—The fields are plowed or spaded, after which the soil masses are broken down into small particles either with a har-

[5]Unfortunately the information on naked barley varieties is far less complete than that for covered varieties.

row or with a hoe. After the soil surface is levelled, fertilizer furrows are made about 3 inches in depth, 6 inches in width, and from 24 to 28 inches apart. The furrows are covered with 1 to 1½ inches of soil after the application of the fertilizers. The seed is then sown in the furrows over the fertilizers and covered with ½ inch of soil (Fig. 4).

FIG. 4.—Sowing barley in Japan.

Fertilizers.—In addition to about 4,500 pounds of barnyard manure per acre, varying amounts of other fertilizers are generally applied to different fields. These fertilizers may include one or more of the following: soybean cake, ammonium sulfate, calcium cyanamide, potassium sulfate, potassium chloride, wood ashes, superphosphate, and human excrement or "night soil". Good farmers use 71 to 89 pounds of nitrogen (N), 45 to 89 pounds of phosphate (P_2O_5), and 71 to 80 pounds of potash (K_2O) per acre, but the best farmers apply even greater amounts of fertilizers.[6] Because of the shortage of commercial fertilizers since the termination of World War II in 1945, farmers applied only about 31 pounds per acre of ammonium sulfate or calcium cyanamide in addition to the basic application of barnyard manure in 1946. Some wood ashes, "night soil", and poultry manure were also available. The barnyard manure is generally applied before seeding, but sometimes a part of it is put on in the spring as a top-dressing. When fertilizers are plentiful, nitrogen fertilizers are used which become available slowly, 50% being applied before seeding and the balance top-dressed in two applications. At the present time only nitrogen fertilizers which become rapidly available are applied in the growing stage as a top-dressing.

[6]SWANSON, C. L. W. Fertilizer practices for the staple food crops in Japan. Proc. Nat. Joint Comm. on Fert. Application. 1946. This paper gives average recommendations for fertilizer applications on an acre basis for barley as follows: 125 pounds nitrogen (N), 67 pounds of phosphate (P_2O_5), and 71 pounds of potash (K_2O). Recommended amounts of fertilizers were generally higher than the amounts actually used.

Rates and dates of seeding.—The rate of seeding varies from 48 to 68 pounds per acre for covered barley, and from 50 to 74 pounds for naked barley. The rate of seeding increases from Kyushu to Hokkaido The seed is generally planted in drills or bands about 4 inches wide. In areas where heaving is common, the seeds are planted in rows 12 to 16 inches apart at the rate of 50 to 60 seeds in a hill.

The date of fall sowing varies in each district, but it is generally seeded earlier in the colder regions to enable the plants to become well established before freezing temperatures occur. The fall crop is generally planted between September 15 and November 30. Spring barley in Hokkaido is usually planted in April (Table 4).

Barley transplanting was practiced to some extent during 1944 and 1945 in a few districts where direct seeding of barley after rice was delayed because of a late rice crop. The seedlings, previously grown in a nursery bed, are transplanted into the drained paddy fields at a later date than would be possible with direct seeding. The method is not widely practiced.

TABLE 4.—*Rates and dates of seeding and time of harvest of barley in Japan.*

District	Planting period	Planting rate, lbs. per acre		Period of harvest
		Covered barley	Naked barley	
Hokkaido	Apr. 20–May 10*	68	74	Aug. 1–20
	Sept. 10–30	68	74	July 10–31
Tohoku	Sept. 20–Oct. 10	58	62	June 10–30
Hokuriku	Oct. 1–20	58	62	June 10–20
Tosan	Oct. 10–31	48	50	June 10–30
Kanto	Oct. 20–Nov. 10	48	50	June 1–20
Tokai	Nov. 1–30	48	50	June 1–20
Kinki	Nov. 10–30	48	50	June 1–20
San-in	Nov. 1–20	48	50	June 1–20
Chugoku	Nov. 10–30	48	50	May 20–June 10
Shikoku	Nov. 10–30	48	50	May 20–June 10
Kyushu	Nov. 20–Dec. 10	48	50	May 20–June 10

*Spring-seeded barley.

Field management.—Two unique cultural methods widely observed in Japan are tramping and mulching with soil which are practiced after the plants send out two or three leaves.

Tramping consists of stepping on the soil and plants with the feet. The reasons usually given for the practice are (1) to keep down a too vigorous top growth, and (2) to prevent damage from heaving. Tramping is less frequently practiced in the warmer districts where heaving seldom occurs or in areas of heavy snowfall.

Soil top-dressing, or mulching with soil, consists of lifting the soil from between the rows with a perforated-bottom shovel and lightly scattering the particles over the plants (Fig. 5). The amount of soil put on the plants varies from ¼ to ¾ inch, usually applied in each of two applications. Mulching appears to be based on the belief that the young plants secure more plant food as a result of the practice. Other reasons given for mulching are to protect the young plants from

severe winter cold to kill late tillers with the soil in order to conserve fertilizers for the early growth, and to prevent lodging.

The barley field is cultivated several times between the ridges. This operation, combined with weeding, is performed with a hoe or by animal-drawn cultivators.

Harvesting.—Most of the barley crop in Japan is harvested in June (Fig. 6 and Table 4). The ripe plants are cut near the soil surface with a hand sickle. The cut grain is generally laid in the swath for

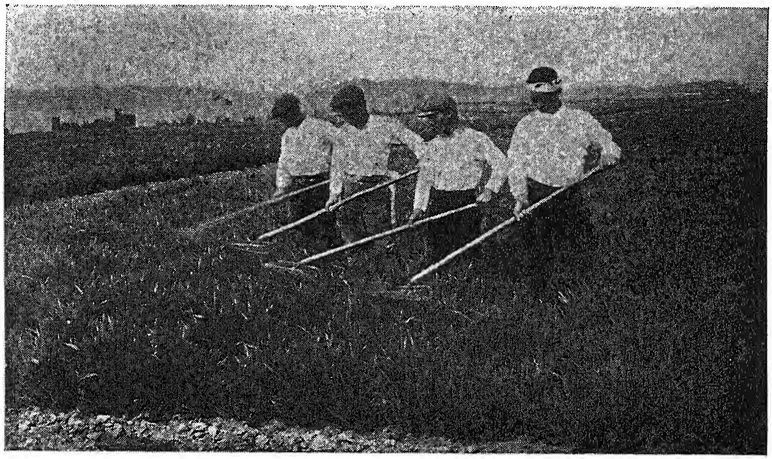

FIG. 5.—Top-dressing of soil on barley plants.

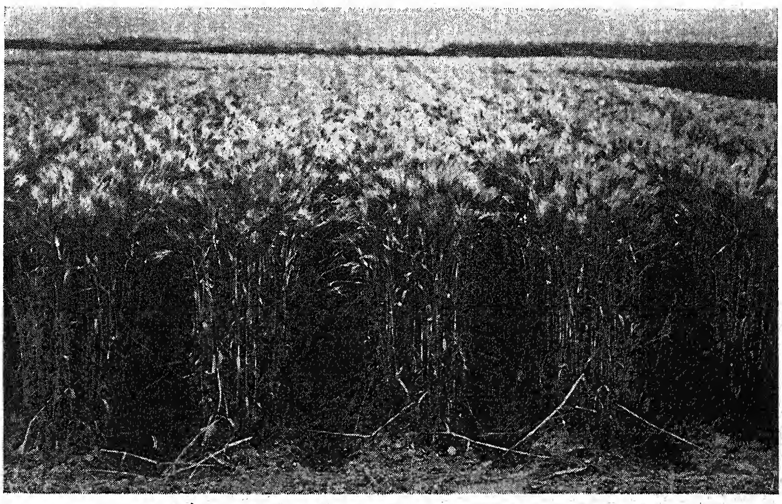

FIG. 6.—Ripening field of barley in Japan.

several days to dry, so-called gi-boshi (Fig. 7). However, in the colder regions, the harvested plants are tied in bundles approximately 8 inches in diameter and hung to dry on horizontal bamboo or wooden frames about 5 feet high.

FIG. 7.—Harvesting barley in Japan.

The dried grain is threshed with a small thresher operated either by footpower or by a gasolene engine or an electric motor. Most farmers own their machines in districts where man-power threshers are popular. The grain is often separated from the chaff by winnowing. This operation is often done by wind or by a hand-operated fan. Engine or motor-powered threshers are often used cooperatively in a village. They generally thresh, remove the chaff, and separate out the light-weight grains in one operation.

The cleaned grain is spread out on straw mats where it is dried to a moisture content of about 13%. The dried grain is packed in bales or in rice-straw bags. The weight of one bale is regulated by law, being 45 kilograms (99.2 pounds) for covered barley and 60 kilograms (132.3 pounds) for naked barley.

CULTURE ON PADDY FIELDS

In the warmer districts of southwestern Japan, barley is generally grown after the rice crop where the paddy fields can be drained readily. While the cultural methods are similar to those followed on upland fields, some practices are unique to paddy fields.

Plowing for seedbed preparation.—Before rice is harvested, the farmers make temporary drainage ditches in the paddy fields in order to dry out the soil. In southern Japan, where barley is seeded late in the fall, the fields are left to dry for several days after harvesting the rice crop. In central Japan, as in the Kanto District, the land is plowed immediately because it is necessary to sow the barley as soon as possible after the removal of the rice crop. Where the land is poorly

drained, as is often the case, the soil is thrown up into ridges of various heights and distances apart. After drying for a few days, the land is harrowed, the ridges repaired with a hoe, and from one to three fertilizer furrows are made on each ridge. The other operations in planting are the same as for upland fields.

The ridges generally vary from 4 to 6 feet apart. The height depends upon the dryness of the soil, being about 2 or 3 inches high in well-dried soils to a height of as much as 16 inches in water-logged soils. The width of the ridge surface ranges from 16 to 40 inches or more. Sometimes very wide ridges or raised beds are made on which the barley crop is planted in 12-inch drills at right angles to the direction of the ridge. Where the soil dries out readily, farmers commonly make temporary drain ditches only around the field and follow the same cultural methods used on upland fields. Where drainage is very difficult, the barley crop may be planted on hoe-constructed ridges 6½ feet apart and 3 feet wide on the top. In spite of the large amount of hand labor, these high ridges have been found to be very efficient in drying the soil during the winter.

Culture on paddy fields without plowing.—In some districts barley is seeded after rice on paddy fields without plowing. This practice was widely advocated during World War II because of labor shortages in the villages. It is adapted to regions where alternation of crops widely prevails, as on the plains of the Chugoku District, and where the limitations of climate make it necessary to plant barley as soon as possible after the removal of the rice crop, as is common in the Kanto District. Several modifications of cultural practices are followed, but all depend upon the dryness of the soil.

The temporary low-ridge method (Uchiyose-maki) consists of preparing with a hoe the locations where plants are to be grown. The farmer then ridges up these locations so that the seeds can be sown on the ridge. The seeds are covered with barnyard manure previously mixed with soil and fertilizer.

Sowing in furrows (Kezuri-maki) is the making of shallow ditches with a hoe where the seeds are to be sown. Otherwise the method is similar to the temporary low-ridge method. It is followed in areas where the soils are dried readily.

Another modification is sowing in holes (Ana-maki). This practice is adapted to districts where the soils are most easily dried. After harvesting the rice, the farmers first kill the weeds in the field. They then make holes between the rice stands with a wooden rod about 1 inch in diameter. Several seeds are sown per hole after the holes are covered with barnyard manure and other fertilizers. Nothing further is done except to remove the large weeds once or twice during the growing period of the crop. This method is practiced only in one locality in Okayama Prefecture.

DISEASES AND INSECT PESTS

In order of their importance, the most serious barley diseases[7] in Japan are snow blight, *Typhula Itoana*, *Fusarium* spp., *Pythium* spp.;

[7]According to H. Asuyama, Professor of Plant Pathology, Faculty of Agriculture, Tokyo Imperial University.

stripe, *Helminthosporium gramineum;* rusts, *Puccinia anomala*, *P. glumarum*, *P. graminis;* powdery mildew, *Erysiphe graminis;* scab, *Gibberella saubinettii;* smut, *Ustilago hordei*, *U. nuda;* footrot, *Corticium gramineum;* and rosette, a virus disease.

Serious outbreaks of scab, stem rust, and yellow rust sometimes occur on barley in southwestern Japan because of the hot humid atmosphere prevalent as the crop approaches maturity. This is particularly true in the south of Shikoku and in Kyushu. Snow blight often causes serious damage in the Tohoku and Hokuriku districts because of the long period of snow cover. The degree of resistance of some covered barley varieties to several diseases is indicated in Table 5.

TABLE 5.—*Disease resistance of covered barley varieties grown in Japan, 1942.**

Prefecture	Variety	Resistance to†				
		Dwarf leaf rust	Powdery mildew	Scab	Cold	Snow cover
Iwate.....	Iwate Manchuria No. 2	S	M	S	S	S
Miyagi....	Miyagi Rokkaku No. 23	—	W	M	—	M
	Miyagi No. 12	W	W	—	S	M
Yamagata	Hosomugi	M	M	—	—	S
Fukushima	Sekitori No. 3	M	W	W	—	M
Ibaragi ...	Chikurin Ibaragi No. 2	M	W	W	W	—
Tochigi ...	Tochigi Sekitori No. 1	W	W	W	W	W
	Tochigi Golden Melon No. 1	S	S	—	W	W
Gumma...	Manriki	S	—	W	S	—
	Sekitori Den No. 2	M	W	W	W	—
Saitama...	Sekitori Saitama No. 1	S	W	W	W	—
Chiba.....	Bozu No. 1	M	W	M	—	—
	Sekitori No. 2	M	W	W	—	—
Kanagawa	Chikurin	S	W	W	W	W
Niigata...	Omugi Sin No. 1	M	M	S	W	M
Fukui.....	Kedaka Rokkaku	M	W	—	W	M
Yamanashi	Suisho Sekitori No. 305	M	W	W	W	W
Nagano...	Bizen-wase	S	M	M	S	W
Gifu......	Tanikaze No. 105	M	W	M	S	—
Shizuoka..	Kuromugi No. 148	M	W	W	W	W
	Shizuoka Shiro-rokkaku No. 1	M	W	M	—	W
Aichi.....	Tanikaze No. 2	M	W	W	S	—
	Yokuzuna	M	W	M	S	—
Mie......	Baitori No. 10	W	W	W	S	—
Shiga.....	Shiga Hachikoku No. 5	M	W	M	—	W
Kyoto....	Wase Golden Melon	S	M	S	W	—
Hyogo....	Hachikoku No. 2	M	W	S	S	—
Hiroshima	Baitori No. 11	W	W	—	S	—
Yamaguchi	Benkai No. 3	W	W	—	S	—
	Hakata No. 2	S	—	—	—	—

*Data from Imperial Agricultural Experiment Station, Nishigahara.
†S = Strong; M = Medium; W = Weak.

Farmers treat their seed with Uspulun or Ceresan at the rate of 1 part of chemical to 1,000 parts of water to control stripe and covered smut. The seed is immersed in this solution for 20 minutes. The

so-called "cold and hot water method" is used to control loose smut. This method is similar to the standard modified hot water treatment followed in the United States. The seeds are first immersed in cold water for 4 hours after which they are placed in hot water at 48°C (118.4°F) for 3 minutes to raise the temperature of the seeds, and finally they are transferred to hot water at 54°C (129.2°F) for 5 minutes. This method is generally performed cooperatively in the villages.

Barley plants are sprayed in the field when outbreaks of yellow rust, leaf rust, powdery mildew, and scab occur. Protection is afforded the plants by spraying with a lime-sulfur solution (0.5° Baume). The spraying of fungicides is generally a cooperative enterprise of the villages, but recently it has become difficult because of the shortage of chemicals. In the areas of heavy snowfall, barley is protected by spraying with bordeaux mixture before the first snow falls. Except in unusual years, the first persistant snowfall can be predicted with sufficient accuracy to make this measure practicable.

There are very few serious insect pests of barley in Japan. In some localities, young plants are damaged by springtails, *Onychiurus* spp., or the larvae of the crane fly, *Tipula aino*. Damage from these pests is confined almost entirely to fields where barley follows rice on wet paddy fields. The leaf-miners are observed over a comparatively wide range in the spring. They are controlled by a nicotine sulfate soap solution applied at the earliest outbreak.

UTILIZATION

The principal uses of the barley crop are for food and forage, as indicated in Table 6. About 75% of the naked barley and 64% of the covered barley was used directly as human food in 1942. Barley is generally preferred to wheat for cooking with rice. It is pearled when used in this manner. Utilization for livestock feed is of minor importance. The straw is used for straw braids, roof-thatching, litter, and for mulches for vegetables.

TABLE 6.—*Uses of barley in Japan, 1942.**

Use	Covered barley		Naked barley	
	Amount, bu.	%	Amount, bu.	%
Meal (eating use)	22,221,998	64.42	22,969,068	75.88
Fodder or feed	7,875,724	22.83	4,346,558	14.36
Seed	1,022,197	2.96	1,024,719	3.39
Bean paste and soysauce	1,032,017	2.99	1,826,392	6.03
Beer	1,722,218	5.00	—	—
Other uses†	620,091	1.80	104,301	0.34
Total	34,494,245	100.00	30,271,038	100.00

*Computed from statistical tables of Japanese foodstuffs (Syokuryo-yeran), Food Control Bureau, Ministry of Agriculture and Forestry, Imperial Japanese Government, 1944.
†Includes candy, medicine, yeast, etc.

GENERAL SUMMARY

Barley is a major crop in Japan. In contrast to the extensive scale on which barley is grown in the United States by use of machinery, the crop is cared for intensively in Japan on small fields almost entirely with hand labor. The crop is heavily fertilized in order to obtain maximum production.

Most of the Japanese varieties are spring types seeded in the fall, particularly in southwestern Japan. Fall seeding is possible there because of the mild winter climate. Except in northern Japan, spring seeding is seldom practiced because of the hot humid summer climate.

Most of the Japanese barley is six-rowed, as in the United States. However, naked barley is more widely grown in Japan than covered barley, largely because the principal use is for human food. In contrast, covered barley is grown almost exclusively in the United States, primarily for livestock feed and for malt.

The Effects of Grazing Winter Small Grains[1]

JOHN B. WASHKO[2]

TENNESSEE farmers, who regularly grow small grains in their rotations, have recognized the value of these crops in providing winter and early spring grazing in addition to grain production. Little data are available, however, to aid these farmers in choosing the proper varieties and in following the most desirable pasturing practices when the various small grains are to be grazed before harvesting for grain. Specifically, information is lacking on (a) which of the small grains produces the largest amount of forage with the least reduction in grain yield; (b) the effects of forage removal on grain yields, tillering, plant height, and ripening; (c) the period in the growing season that each provides maximum forage; and (d) the value of erect types of grain as compared with prostrate types for pasture purposes. The latter is also of interest to small grain breeders in evaluating varieties for pasture purposes and grain production.

A review of the literature discloses that several workers (1,2,3,4,5, 11,12)[3] have contributed to various phases of the above problems. The most recent are Staten and associates (6, 7,8,9,10) at Oklahoma. There appears to be little information, however, on the growth habits of the small grains during their early stages of growth in relation to their suitability for pasture purposes, which is the subject of this paper.

MATERIALS AND METHODS

A variety of each of the winter small grains representing an erect and a prostrate type was used in this experiment. The varieties used and their growth habits were as follows: Rye, Balbo (erect) and Hiwassee[4] (semi-prostrate); barley, Missouri Early Beardless (erect) and the Jackson strains[5] (prostrate); wheat, Carala (erect) and Fulcaster No. 612 (prostrate); oats, Fulgrain (erect) and Fulwin (prostrate). Each variety was seeded at the rates recommended for grain production, i.e., rye at 1½ bushels per acre, barley and oats at 2 bushels per acre, and wheat at 1¼ bushels per acre. The soil type was a Cumberland silt loam of medium fertility. A 3-12-6 fertilizer was applied at the rate of 300 pounds per acre at time of seeding. Each of the small grains was seeded September 7 on 1/20-acre plots, replicated three times. The experiment was laid out as a split-plot design. The main plots were planted to different varieties to permit comparisons between erect and prostrate varieties of each small grain. Each main plot was divided into two sub-plots to permit a comparison of each variety under grazed and and ungrazed conditions.

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[2]Formerly Associate Agronomist, Tennessee Agricultural Experiment Station; now Associate Professor of Agronomy, Pennsylvania State College and Experiment Station State College, Pa.

[3]Figures in parenthesis refer to "Literature Cited", p. 666.

[4]This variety proved to be only semi-prostrate rather than prostrate, as first designated.

[5]The Jackson strains, Jackson and Jackson No. 1, were "sister" selections and similar in growth characteristics. The former was used during the first year of the experiments, 1943-44, and the latter during the other two years 1944-45 and 1945-46.

Grazing was with sheep, the number so adjusted as to remove the available forage in 24 hours, and varied from four to six per each type of grain. During the first year the sheep were given free choice in grazing, and in the following two years each of the small grains was fenced separately to prevent selective overgrazing. A measure of the forage removed was obtained by means of pasture cages. Each small grain was grazed once in the fall and once in the spring. Fall grazing was practiced during the first week in November, and spring grazing was completed by March 15.

Height measurements were taken to tips of the leaves before both the fall and spring grazing. Observations were made as to the location of the growing point before the spring grazing and on forage palatibility of the various grains. Height measurements and tiller counts[6] were made at five different locations within each plot at time of ripening. Plant heights were expressed to the nearest ½ inch, while tiller counts were expressed as the number per linear foot of drill row.

The effect of grazing on date of ripening was also noted. Yields of grain were determined on both the grazed and ungrazed portions of each plot. The three year's data on forage yields, grain yields, plant height, and number of productive tillers were analyzed statistically according to the variance method for all varieties except Fulgrain oats. This variety killed out badly after the spring grazing during the first year of the experiments, and except for forage and grain yields, represent only two years' data. The forage obtained from the individual plots of each grain were composited and a representative sample was obtained for chemical analyses. Crude portein, calcium oxide, and phosphoric acid contents[7] of the forage were determined according to methods prescribed by the Association of Official Agricultural Chemists.

RESULTS

The stage of growth at time of grazing and the amount of forage removed by fall and spring grazing from each grain are given in Table 1. In the fall the Fulgrain oat variety and the Jackson barley varieties were tallest when grazed, with only minor differences in plant height among the other varieties. At the time of spring grazing the rye was tallest, the wheat next tallest, and the oats shortest. As indicated by the location of the growing points with respect to the soil surface, the rye was at a more advanced stage of growth than the other small grains in the spring, and the erect varieties were a little farther advanced than the prostrate varieties.

As regards fall forage production, the wheat was lowest and the rye, barley, and oats produced approximately equal amounts. In the spring the rye furnished the largest amount of forage, the barley and wheat the next largest, and the oats the smallest amount.

When these forage yields are related to season of production, it is found that the oat and barley varieties produced the greater proportion of their total forage in the fall, 52.8% and 42.4%, respectively, as compared to 35.6% and 34.8% for the rye and wheat varieties, respectively. Similarly, the wheat and rye varieties produced more of their forage during the spring season, 65.2% for the wheat and 64.4% for the rye, as compared to only 57.6% for the barley and 47.3% for the oat varieties. Rye outyielded the other small grains in total forage production. The barley, wheat, and oat total forage yields were of approximately the same order, with statistically significant differences occurring only between the Jackson strains of barley, Ful-

[6]Only those tillers were counted which produced a culm with a "head" and are herein referred to as productive tillers.

[7]The writer wishes to acknowledge his indebtedness to K. B. Sanders, Associate Chemist, for the chemical determinations.

TABLE 1.—*Stage of growth and dry forage yields of small grains when grazed, 1943–46.**

Variety	Habit of growth	Plant height, in.		Location of growing point with respect to soil surface in spring	Air-dry forage removed—per acre, lbs.†		
		Fall	Spring		Fall	Spring	Total
				Rye			
Balbo	Erect	9.5	14.0	2.5 to 5.0 inches above	711	1,347	2,058
Hiwassee	Semi-prostrate	8.5	15.5	2.5 to 5.0 inches above	732	1,266	1,998
				Barley			
Mo. Early Beardless	Erect	9.5	7.0	0.5 to 1.0 inches above	638	933	1,571
Jackson strains‡	Prostrate	12.0	8.0	0.0 to 0.5 inch above	733	927	1,660
				Wheat			
Carala	Erect	9.5	11.5	0.0 to 1.0 inch above	508	1,096	1,604
Fulcaster No. 612	Prostrate	10.0	9.0	At or below	535	874	1,409
				Oats			
Fulgrain	Erect	12.5	7.0	0.0 to 1.0 inch above	804	603	1,407
Fulwin	Prostrate	7.0	4.0	At or below	719	768	1,487

*Each figure is the average of three replicates for three years.
†Least significant difference at 5% point for varieties and grazing periods 241 pounds.
‡Jackson in 1943–44; Jackson No. 1 in 1944–46.

caster No. 612 wheat, and Fulgrain oats. Forage differences between erect and prostrate varieties of the same small grain were minor and statistically nonsignificant. Growth habit, therefore, did not appear to be directly related to forage production.

The effects of grazing on grain yields, plant height, tillering, and maturity of the small grains are shown in Table 2. Grazing reduced grain yields of all varieties and of all small grains significantly. The Missouri Early Beardless barley was injured most severely and Fulcaster No. 612 wheat the least by grazing. On a percentage-basis this reduction amounted to 46.7% for the former and 23.2% for the latter. For the remaining varieties of the various small grains the reduction ranged from 28.2% to 38.6%. Except in the case of rye, growth habit was directly related to the amount of injury suffered by the various varieties as indicated by grain yield reduction. The prostrate growing types suffered less reduction in grain yield than the erect types.

Plant height of all varieties of the small grains was reduced by grazing as indicated in Table 2. This reduction in plant height ranged from 12.0% for the Hiwassee rye to 18.9% for Carala wheat. Growth habit again appeared to be related to plant height reduction due to grazing since the height of erect varieties was reduced more than that of the prostrate types. These differences, however, were not as pronounced as in the case of grain yield.

Tillering of all varieties was also reduced as indicated in Table 2. Reduction in the number of productive tillers was not consistently related to habit of growth. In the case of erect varieties of rye and oats, the number of tillers was reduced more than that of the corresponding varieties with prostrate growth, but the reverse was true in the case of barley and wheat.

Dates of ripening of the various small grains were postponed an average of 4 to 8 days by grazing, depending upon weather conditions.

An indication of the nutritive value of the forage removed by grazing is given in Table 3, reporting the chemical composition of the forage for the year 1945–46. The fall-produced forage was more succulent than the spring-produced forage irrespective of type of grain or variety, as indicated by the smaller percentage of dry matter. The fall forage was found to be more nutritious than the spring forage as indicated by crude protein and mineral content. On a moisture-free basis the crude protein content of the fall forage ranged from a low of 23.9% for the Jackson No. 1 barley variety to a high of 30.9% for the two wheat varieties, as compared with the spring forage which ranged from 12.8% for the Jackson No. 1 barley to 19.8% for Fulcaster No. 612 wheat. The fall-grown forage, considering all small grains and varieties, averaged 12.4% more protein than spring-grown forage. Differences in protein content between varieties of the same small grain were minor, except for Jackson No. 1 barley which was lower in protein content than Missouri Early Beardless in both fall and spring. The protein content of the forage of Jackson No. 1 barley was also lowest of all the small grain varieties used in this experiment both in the fall and spring.

As regards calcium oxide (CaO) content, again the fall forage was higher than the spring forage. The fall forage averaged 0.47% more

TABLE 2.—*Effect of grazing on grain yields, plant height, tillering, and maturity of small grains, 1943–46.**

Variety	Grain yields per acre, lbs.		Plant height at harvest, in.		Number of productive tillers		Number days delay in ripening caused by grazing	Reduction due to grazing, %		
	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed		Grain yield	Plant height	Number productive tillers
Rye										
Balbo	2,119	1,307	68.5	59.5	31	24	5	38.3	13.1	22.6
Hiwassee	2,000	1,235	71.0	62.5	31	25	4	38.3	12.0	19.4
Barley										
Mo. Early Beardless	1,683	897	43.5	36.0	26	22	8	46.7	17.3	15.4
Jackson strains†	2,013	1,237	41.5	35.0	28	23	5	38.6	15.7	17.9
Wheat										
Carala	1,610	1,061	53.0	43.0	34	27	5	34.1	18.9	20.6
Fulcaster No. 612	1,470	1,129	59.0	52.0	28	21	6	23.2	11.9	25.0
Oats										
Fulgrain	1,734	1,071	(43.5)	(36.5)	(31)	(24)	(6)	38.2	16.1	22.6
Fulwin	2,149	1,544	57.0	50.0	25	23	5	28.2	12.3	8.0
L.S.D. 5% point:										
For varieties	337 lbs.		3.0		3.5					
For treatment	217 lbs.		1.8		2.3					

*Each figure is the average of three replicates for three years, except those in parenthesis which are for two years and are not included in the statistical analysis of the data.

†Jackson in 1943–44; Jackson No. 1 in 1944–46.

TABLE 3.—*Chemical composition of fall and spring small grain forage, 1945–46.**

Variety	Dry matter, %		Crude protein, %		CaO, %		P_2O_5, %	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
				Rye				
Balbo	16.8	20.8	30.1	18.7	1.05	0.43	0.87	0.62
Hiwassee	17.5	20.5	29.8	18.0	1.12	0.44	0.78	0.61
				Barley				
Mo. Early Beardless	16.4	23.2	27.9	16.6	1.03	0.45	0.70	0.56
Jackson No. 1	16.1	22.0	23.9	12.8	1.17	0.58	0.68	0.48
				Wheat				
Carala	16.8	18.5	30.9	17.3	1.00	0.54	0.81	0.56
Fulcaster No. 612	18.3	20.6	30.9	19.8	0.94	0.50	0.76	0.57
				Oats				
Fulgrain	17.9	21.9	29.3	15.1	0.73	0.50	0.65	0.45
Fulwin	19.4	23.4	30.1	15.2	0.63	0.47	0.71	0.46

*Analyses reported on moisture-free basis.

CaO than the spring forage. The forage of both oat varieties was lower in calcium content than any of the other small grains in the fall, whereas only minor differences existed in the spring between the various small grain varieties with respect to this mineral. Similarly, the phosphoric acid (P_2O_5) content of fall forage was higher than that of the spring forage, with only minor differences occurring between the various small grains and between varieties. The fall forage contained an average of 0.21% more P_2O_5 than the spring forage.

OBSERVATIONS ON PALATABILITY

Observations on palatability disclosed that, when given free choice, the sheep preferred oats to the other small grains, both in the fall and spring. Barley was their next choice in both fall and spring. In the fall, wheat was preferred to rye, whereas in the spring the reverse was true.

Varietal preferences were also noted in some of the grains, but the preferences did not appear to be associated with type of growth and did not appear to be consistent. In the case of the ryes, no preference was noted for either variety. Missouri Early Beardless barley was preferred to Jackson and Jackson No. 1 at all times. Fulcaster No. 612 wheat was preferred to Carala in two out of three years. In the case of the oats, Fulgrain was preferred to Fulwin in all three years.

DISCUSSION

Time of seeding is an important factor if small grains are to be grazed. Unless the small grains are seeded in Tennessee by the first week in September, they will not make sufficient growth to permit

both fall and spring grazing. Early seedings, however, expose the small grains to certain leaf diseases in the fall. In one of the three years the barley was affected with leaf rust and the oats with Helminthosporium leaf blotch. This early seeding of wheat also exposes it to attacks by the Hessian fly, since the earliest recommended date for seeding wheat in Tennessee is not until October 10. While no trouble had been experienced in this respect in any of the three years of this experiment, the danger of Hessian fly infestation nevertheless existed.

Forage yields of erect and prostrate types were approximately the same, but reductions in grain yield were greater in the case of the erect types. The possible explanation for the greater reduction in grain yields suffered by the erect varieties as compared with the prostrate types is that the erect types were at a more advanced stage of growth, as indicated by the location of the growing points, and injury was therefore greater.

As indicated by the one year's data on chemical composition, fall forage differed markedly from the spring forage in quality. These differences appear too large to be explained entirely on the basis of stage of growth. Undoubtedly the higher protein and mineral content of the fall forage is due in part to the larger supply of plant nutrients available in the fall as a result of fertilization. Spring forage is thus produced with a lower level of plant nutrients which, in turn, is reflected in lower protein and mineral content.

A promising field for investigation is suggested with the small grains to determine the proper fertilization practices necessary to obtain maximum yields of highly nutritious forage with a minimum reduction in grain yield.

While this investigation shows that forage removal is detrimental to grain production, the loss of grain is compensated for by the value of the high quality forage removed; particularly since this forage is available at a period when it saves considerable barn feeding.

SUMMARY

Two varieties representing erect and prostrate types of each of the winter small grains, oats, barley, wheat, and rye, were grazed with sheep at Knoxville, Tenn. during the years 1943–44, 1944–45, and 1945–46 to determine the effects of this forage removal on subsequent grain yields, plant height, tillering, and maturity.

The rye, barley, and oats produced approximately equal amounts of forage in the fall, whereas the wheat produced the least fall forage. In the spring the rye furnished the largest amount of forage, the barley and wheat next largest, and the oats the smallest amount. In total forage production, rye out-yielded the other small grains with only minor differences in total forage yields occurring between barley, wheat, and oats. Differences in forage production between erect and prostrate varieties of the same small grains were minor and did not appear to be related to growth habit.

Grazing with sheep as practiced in these experiments was detrimental to grain production of all the four small grains. On a percentage

basis this reduction in grain yield ranged from a low of 23.2% to a high of 46.7%, depending upon the variety and kind of small grain. Except for rye, growth habit was directly related to grain yield reductions caused by grazing. The prostrate growing types suffered less reduction than the erect types.

Grazing also reduced plant height and tillering and postponed ripening from 4 to 8 days. As regards these characteristics, growth habit was associated only with plant height reduction; as in the case of grain yield, the height of prostrate varieties was reduced less by grazing than that of erect varieties.

As indicated by chemical analyses of the forage obtained only in 1945–46, small grain forage is high in protein, calcium, and phosphorus. Fall forage proved to be superior to spring forage in the components mentioned.

Observations on palatability indicated that oats were preferred by sheep to the other small grains. The palatability relationships of the other small grains and of the varieties themselves were not clear, since the sheep were inconsistent in their preferences. There did not appear to be any direct association between palatability of the various varieties and their growth habits.

LITERATURE CITED

1. FINNELL, H. H. Winter grain pasture yield and utilization. Okla. Panhandle Exp. Sta. Bul. 4. 1929.
2. GEORGESON, C. C., BURTIS, F. C., and SHELTON, W. Experiments with wheat. Kans. Agr. Exp. Sta. Bul. 33. 1892.
3. ————, ————, and OTIS, D. H. Experiments with wheat. Kans. Agr. Exp. Sta. Bul. 59. 1896.
4. KIRK, L. E., DAVIDSON, J. G., and HAMILTON, S. N. Cereal grain crops for annual pasture. Sci. Agr., 14:569–579. 1934.
5. STANSEL, R. H., DUNKLE, P. B., and JONES, J. L. Small grains and ryegrass for winter pasture. Tex. Agr. Exp. Sta. Bul. 539. 1937.
6. STATEN, H. W. Palatability test of winter pasture crops. Okla. Agr. Exp. Sta. Mimeo. Circ. M–115. 1944.
7. ————, *et al.* Forage production of small grain and ryegrass. Okla. Agr. Exp. Sta. Mimeo. Circ. M–114. 1944.
8. ————. Grazing trials: Winter small grains and ryegrass. Okla. Agr. Exp. Sta. Mimeo. Circ. M–142. 1945.
9. ———— and MUNCRIEF, E. H. Forage production of winter small grain varieties and annual ryegrass. Okla. Agr. Exp. Sta. Mimeo. Circ. M–143. 1945.
10. ———— and ELDER, W. C. Forage production of winter small grain varieties and annual ryegrass and effect of clipping upon grain yields. Okla. Agr. Exp. Sta. Mimeo. Circ. M–161. 1946.
11. SWANSON, A. F. Pasturing winter wheat in Kansas. Kans. Agr. Exp. Sta. Bul. 271. 1935.
12. TROTTER, I. P. Oat varieties for winter pasture production. Jour. Amer. Soc. Agron., 34: 292–294. 1942.

A Biometric Evaluation of the Growth-Regulating and Herbicidal Properties of Some Organic Compounds[1]

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THE literature covering the action of organic chemicals having growth-regulating properties is extensive. The recent paper of Thompson, Swanson, and Norman[3] presents a comprehensive review of all the modern work from 1931 through the early months of 1946. In addition, the activities of 1,160 new compounds are described and classified using 2,4-dichlorophenoxyacetic acid as a standard.

Beginning in the summer of 1945, workers at the Colorado Agricultural Experiment Station began a search for new chemicals suitable for use as herbicides, plant growth-regulators, and inhibitants. Up until the present time, most of the emphasis has been placed on the search for herbicidal materials that are either more specific or more active than 2,4-dichlorophenoxyacetic acid. The objectives of this report are to present a biometric evaluation of the primary growth-regulating properties of a group of organic compounds as measured by a modification of Went's pea test and to evaluate the herbicidal action of many of the same compounds as shown by a standard test on castor beans under greenhouse conditions.

METHODS

THE SPLIT PEA STEM TECHNIQUE

Went's pea test modified to meet the conditions of this study was used to determine primary growth-regulating properties of all compounds studied. This test is based on the fact that chemical solutions with growth-regulating properties cause inward curvatures of the terminal sections of young split pea stems. The procedures used for growing, sectioning and testing the peas were those outlined by Went and Thimann,[4] except that no corrections for variation in pH were made. Each compound was tested over a range of 13 concentrations that varied

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[2]Associate Botanist and Associate Chemist, respectively. The authors gratefully acknowledge the assistance of Andrew G. Clark, Professor of Mathematics, for his guidance in the statistical analyses of the data; of Mrs. Nellie Landblom for technical assistance; and of Mrs. Patricia Wilson and Miss Madaline Worley for laboratory assistance.

[3]THOMPSON, H. E., SWANSON, CARL P., and NORMAN, A. G. New growth-regulating compounds: I. Summary of growth inhibitory activities of some organic compounds as determined by three tests. Bot. Gaz., 107:476–507. 1946.

[4]WENT, F. W., and THIMANN, KENNETH V. Phytohormones. New York: The Macmillan Co. 1937.

from 0.000029 M to 0.122000 M.[5]

This particular range of concentrations was selected because of its relationship to the sodium salt of 2,4-dichlorophenoxyacetic acid expressed in parts per million, i.e., 0.000029 M corresponds to 8 p.p.m. and 0.122000 M to 31,942 p.p.m. Concentration No. 8, i.e., 0.003812 M corresponds to 995 p.p.m. which is close to 1,000 p.p.m., the common concentration used in herbicidal studies. Concentration No. 8 for 2,4-dichlorophenoxyacetic acid is the equivalent of 843 p.p.m. This variation, on the parts per million basis, is due to differences in the molecular weights of the two compounds. A comparison of the monohydrated form of the sodium salt of 2,4-dichlorophenoxyacetic acid and of 2,4-dichlorophenoxyacetic acid at all 13 concentrations is shown in Table 1.

TABLE 1.—*Comparison of monohydrated form of sodium salt of 2,4-D and of 2,4-D acid at 13 concentrations.*

No.	Molar concentration	Parts per million concentration	
		2,4-dichlorophenoxyacetic acid, molecular weight = 221	Sodium salt of 2,4-dichlorophenoxyacetic acid, monohydrated, molecular weight = 261
1	0.000029 M	7	8
2	0.000059 M	13	16
3	0.000119 M	26	31
4	0.000238 M	53	62
5	0.000476 M	105	124
6	0.000953 M	211	249
7	0.001906 M	421	498
8	0.003812 M	843	995
9	0.007625 M	1,685	1,990
10	0.015250 M	3,370	3,980
11	0.030500 M	6,741	7,960
12	0.061000 M	13,481	15,921
13	0.122000 M	26,962	31,942

This illustrates the fact that equimolar concentrations of two similar compounds differ significantly on a parts per million basis. Conversely, it could be shown that equal concentrations on a parts per milliom basis differ on a molar basis.

In the preparation of test solutions, the highest concentration was made by direct weighing and making up to volume. All other concentrations were made by dilution in such manner that each succeeding dilution was one-half as concentrated as the preceding one. Tests made on a parts per million basis or on a percentage basis, whether it be a volume or weight basis, are misleading. Distilled water was used as a solvent in all cases where the chemical was readily water soluble. Compounds not water soluble were dissolved in 10 times their weight of Carbowax 1,500 if not otherwise stated and made up to volume with distilled water. Compounds were tested on a molar basis because this seemed to be the only adequate method of comparing unrelated chemicals with large molecular weight differences.

[5]For the sake of brevity, numbers were assigned to each concentration as follows:

No.	Concentration	No.	Concentration	No.	Concentration
1	0.000029 M	5	0.000476 M	9	0.007625 M
2	0.000059 M	6	0.000953 M	10	0.015250 M
3	0.000119 M	7	0.001906 M	11	0.030500 M
4	0.000238 M	8	0.003812 M	12	0.061000 M
				13	0.122000 M

Six chemicals were tested each week during the period from October 1, 1945, to December 1, 1946. At each test date, the compound, 2,4-dichlorophenoxyacetic acid dispersed in 10 times its weight of Carbowax 1,500 and made up to volume with distilled water was used as a standard of comparison. This was done to eliminate most of the error due to minor variations in the physiological condition of the peas from one test date to the next.

Ten pea stems were used for each concentration of each compound tested. Quantitative data were secured by classifying the amount of curvature in each stem as shown in Fig. 1.

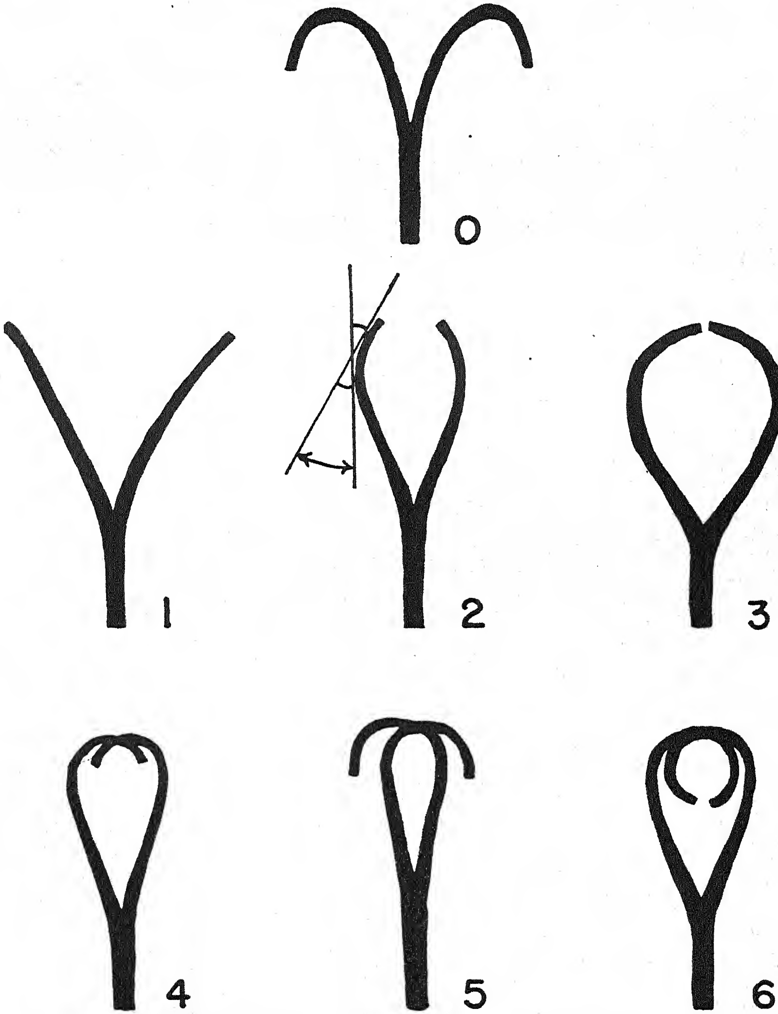

FIG. 1.—Pea stem growth-curvature classes. 0 = Zero inward curvature, typical of distilled water; 1 = Slight inward curvature; 2 = Tips parallel to an inward curvature of 45°; 3 = Average inward curvature between 45° and 90°; 4 = Average inward curvature between 90° and 135°; 5 = Average inward curvature between 135° and 180°; 6 = Average inward curvature greater than 180°.

THE CASTOR BEAN TEST FOR HERBICIDAL ACTION

In selecting a plant for greenhouse culture adapted to tests of herbicidal action, consideration was given to ease of culture during all months of the year, sensitivity to both high and low concentrations of spray applications of 2,4-dichlorophenoxyacetic acid, and plant uniformity. Of the ten annual and three perennial species investigated in preliminary trials, castor beans met the requirements best.

Test plants were grown in a warm greenhouse where the daily variation in temperature was between 70° and 85° F. Plants were grown in 4-inch pots, one plant per pot. The texture of the soil used was a sandy loam. Plants were watered to maintain a rapid rate of growth. When the plants reached an average height of 12 inches, usually 5 to 6 weeks after planting, they were sorted for uniformity and then sprayed with solutions of the various chemicals.

Spraying was done in a closed chamber equipped with a wall suction fan to remove excess spray. Care was taken to aerate the chamber thoroughly between spray operations to reduce to a minimum errors due to handling different chemicals. Spraying was accomplished by use of a simple sprayer of an atomizer type attached to an air pump and equipped with a glass intake tube that could be easily cleaned between concentrations and chemicals. Plants were then allowed to grow for a 21-day period, after which an evaluation of herbicidal effects was made. This was done by comparing the action of new chemicals with that of 2,4-dichlorophenoxyacetic acid. Comparisons were made over a range of concentrations that varied from 0.000029 M to 0.122000 M.

Three plants were used for each concentration test. Since one of the objectives of this study was to discover chemicals with responses similar to those of 2,4-dichlorophenoxyacetic acid, emphasis was placed on such telemorphic reactions as top bending, petiole bending, secondary root stimulation, stem splitting, and sloughing of the cortex.

The response of castor bean plants to a wide range of concentrations of 2,4-dichlorophenoxyacetic acid are shown in Table 2. This is the standard with which all other chemicals were compared. These responses are further illustrated in Figs. 2, 3, 4, and 5.

TABLE 2.—*The response of castor beans to spray applications of 2,4-dichlorophenoxyacetic acid.*

No.	Concentration	Kind of herbicidal action*	Intensity of herbicidal action†
1	0.000029 M	B, E, I	4
2	0.000059 M	A, B, E, G, I	5
3	0.000119 M	A, B, E, G	6
4	0.000238 M	A, B, E, G, N	7
5	0.000476 M	A, B, E, G, N	7
6	0.000953 M	A, B, E, G, N	7
7	0.001906 M	A, B, E, N	9
8	0.003812 M	A, B, E, N	9
9	0.007625 M	A, B, E, N	9
10	0.015250 M	A, B, E, N	10
11	0.030500 M	A, B, E, N	10
12	0.061000 M	A, B, E, N	10
13	0.122000 M	A, B, E, N	10

*The plant reactions corresponding to these letters are: A = Top bending; B = Petiole bending; E = Wilting; G = Stem splitting; I = Secondary root stimulation; N = Sloughing of the cortex.

†The ten classes of herbicidal reaction-intensity used were: 0 = Plant normal, fully turgid, leaves green; 1 = Slight petiole bending of less than half the leaves; 2 = All petioles bent; 3 = All petioles bent, slight secondary root stimulation; 4 = All petioles bent, pronounced secondary root stimulation; 5 = Top bending, all petioles bent, slight secondary root stimulation; 6 = Top and petioles bent, stem-swelling and splitting present; 7 = Top and petioles bent, lower stem and root cortex sloughed, slight stem-swelling and splitting; 8 = Same as No. 7 except no stem swelling and splitting; 9 = Leaves wilted, stems flaccid, lower stem and root cortex sloughed leaves and stems with slight traces of green color left; 10 = Same as No. 9 except stems and leaves yellow to dark brown, plant dead.

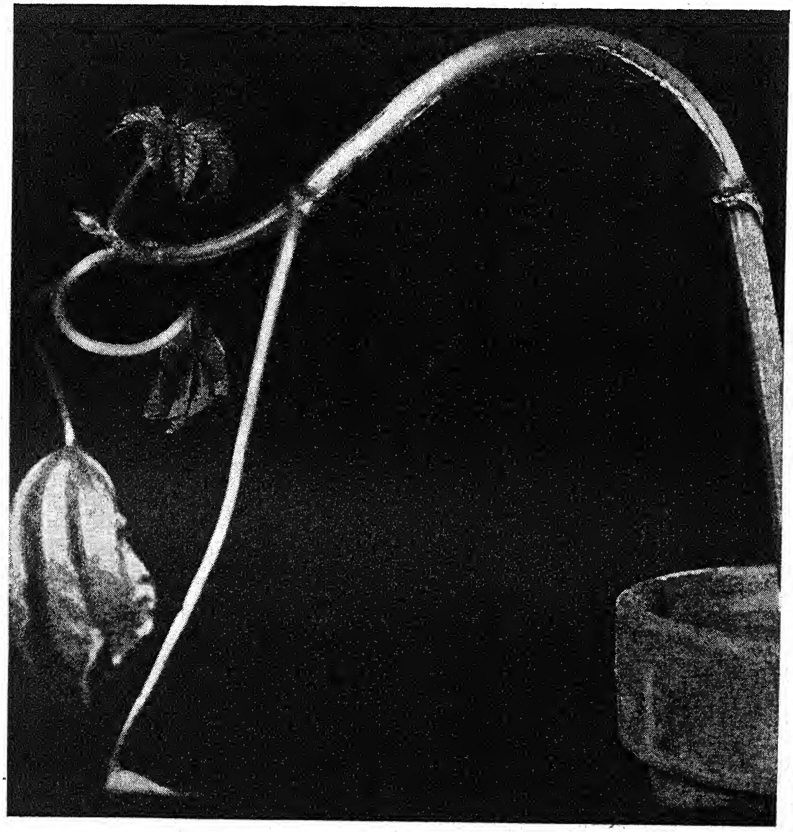

FIG. 2.—The response of castor beans to spray applications of 2,4-dichlorophenoxyacetic acid. Top and petiole bending are shown.

RESULTS AND DISCUSSION

In studying the pea stem growth-curvature results, variance analyses were made for each compound and the check, 2,4-D, in order to eliminate error due to treatments and within treatments. Then the criterion, or d-value, of significance of difference between means of each pair was found. To facilitate the reading of these differences, graphs were made of the differences between the two means at each concentration and the criteria or d-lines were drawn at .05 and .01 levels.

To illustrate this procedure, a variance analyses of alpha-(phenoxy) propionic acid and 2,4-D is shown in Table 3, together with the criterion of significance of difference between means. The pea reaction curves of the same two compounds plotted against concentration are shown in Fig. 6. The significance of the differences in the two curves at any particular concentration can be determined by reference to Fig. 7. All values for alpha-(phenoxy) propionic acid which differ

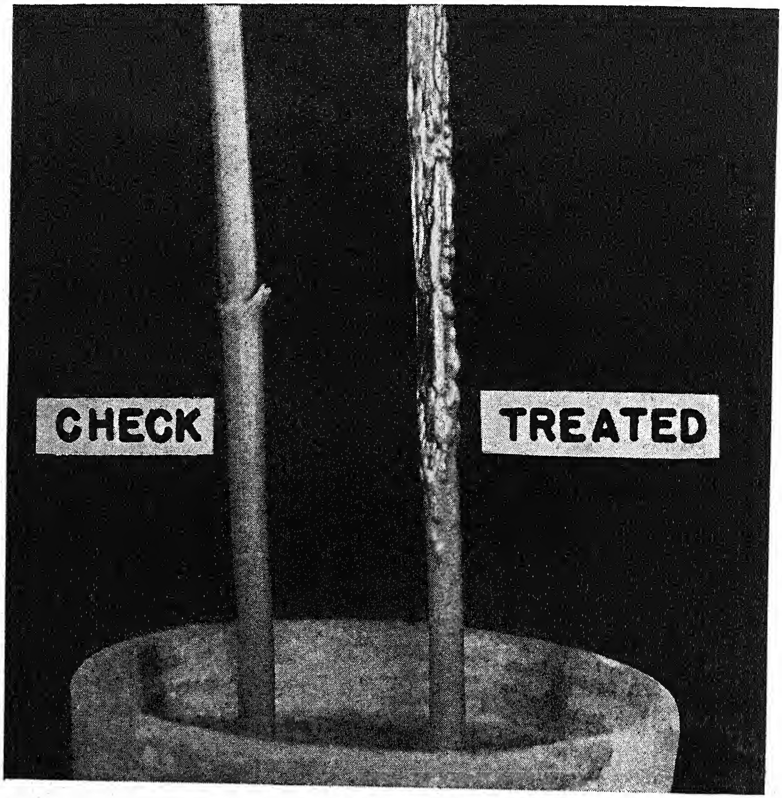

FIG. 3.—The response of castor bean plants to spray applications of 2,4-dichlorophenoxyacetic acid characteristic of concentrations between 0.00095 M to 0.0000953 M. The reaction shown is stem splitting.

from the straight line on the X-axis, the 2,4-D reaction, by an amount equal to either the .05 or .01 d-lines are considered significant.

A similar procedure was used to study the other compounds investigated. In all cases where the observed F value was significant for both treatment and concentration, the criterion of significance was determined. The results for all compounds are shown in Tables 4 to 10, inclusive. Chemicals were classified according to their significant superiority to 2,4-D. This grouping was arbitrary and might have been done in other ways just as well. All chemicals listed in Table 4 have superior growth-regulating properties when compared to 2,4-D, over the whole concentration range of the pea test.

Tables 5, 6, and 7 include those compounds with superior growth-regulating properties in the high, middle, and low concentrations, respectively. Table 8 includes chemicals not significantly different from 2,4-D over the whole concentration range. Tables 9 and 10 include those compounds with inferior growth-regulating properties as compared to 2,4-D.

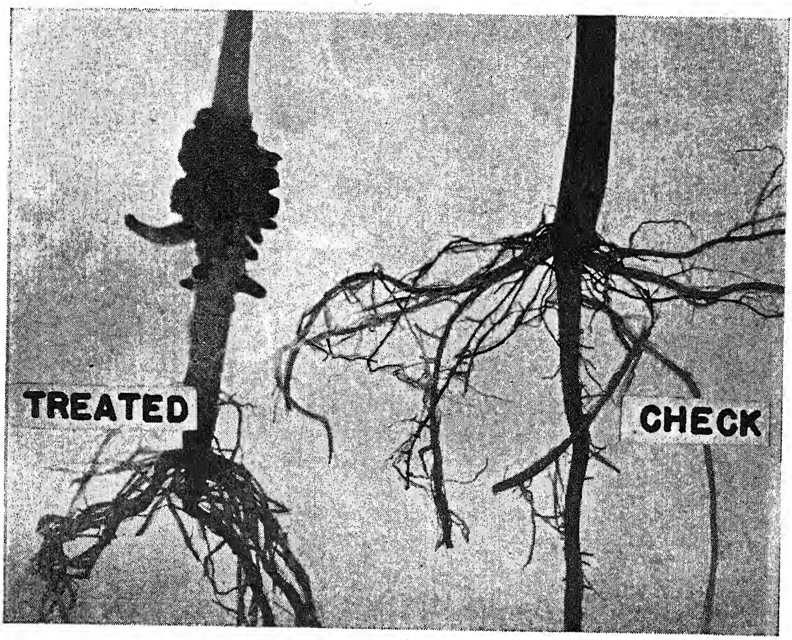

FIG. 4.—Secondary root stimulation from the lower parts of the stem of castor beans. This is characteristic of spray applications of 2,4-dichlorophenoxyacetic acid in the concentration range 0.000029 M to 0.000059 M.

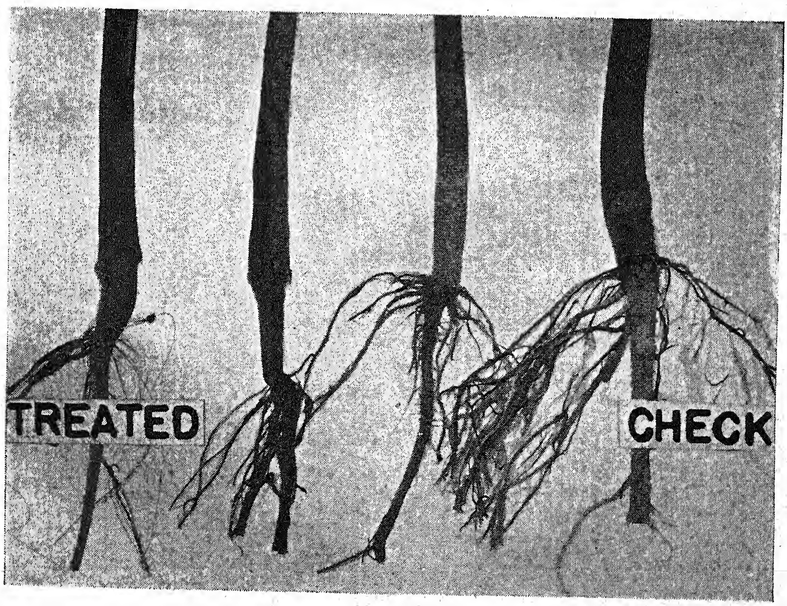

FIG. 5.—Sloughing of the cortex of castor beans and roots characteristic of 2,4-dichlorophenoxyacetic acid concentrations above 0.000238 M.

TABLE 3.—*A variance analysis of the pea stem growth curvatures caused by 2,4-dichlorophenoxyacetic acid and alpha-(phenoxy)propionic acid.*

Variability due to	Sum of squares	D/F	Mean square variance	Observed F	Required F	
					At 0.05	At 0.01
Treatments......	35.26	1	35.2600	26.641	3.89	6.75
Concentrations ..	207.63	11	18.8755	14.262	1.83	2.33
Residual (error)..	300.44	227	1.3235	—	—	—
Totals.........	543.33	239	—	—	—	—

Since the observed F values were significant, the criterion of significance was determined as follows:

Generalized standard error $(\sigma) = \sqrt{1.3235} = 1.1504$

Standard error of difference between 2 means $= \frac{\sqrt{2}}{\sqrt{10}} \cdot \sigma = \sqrt{\frac{1.3235\,(2)}{10}} = \sqrt{.2647} = .51449$

Criterion for significance: $d_{.05} = 2.101(.51449) = 1.081$

$d_{.01} = 2.878(.51449) = 1.481$

TABLE 4.—*Chemicals with significantly superior growth-regulating properties in all concentrations of the pea test.*

Chemical	Chem. No.	Concentrations[1]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
		**	**	*					**	**	**			
Alpha-(2,4,5-trichlorophenoxy) propionic acid[2]	93	S	S	S	I	I	S	S	S	S	S	S	S	S
					**	**	**	**	**	*				
Alpha-(2,4,5-trichlorophenoxy) propionic acid dissolved in triethanolamine[2]	164	S	S	S	S	S	S	S	S	S	S	S	S	S
				**	**	**	**	*	*					
Amine salt of 2,4-dichlorophenoxy-acetic acid[12]	152	S	S	S	S	S	S	S	S	S	I	S	—	—
		**		**		**			*	**		*		
Ammonium salt of 2,4-dichloro-phenoxyacetic acid[13]	149	S	S	S	—	S	I	S	S	S	S	S	—	—
		*	**	**	*	**	**	**	**					
2,4-dichlorophenoxyacetic acid dissolved in triethanolamine[2]	153	S	S	S	S	S	S	S	S	S	I	I	—	—
					*	*	**	**	**	*				
P-nitrobenzeneaso-alpha-naphthol[9]	200	S	S	—	S	S	S	S	S	S	S	—	—	I
							*	**			**			
Phenetole[9]	157	—	S	S	S	S	S	S	S	S	S	S	S	I
						*	*	**	**	**	**	**	**	**
Trimethylene glycol[9]	155	S	S	S	—	S	S	S	S	S	S	S	S	I
						**		**	*			**		
Sodium salt of 2,4-dichlorophenoxy-acetic acid, monohydrate[6]	147	I	S	S	S	S	S	S	S	S	S	S	—	—
		**	**	**	**					**				
P-chlorophenoxyacetic acid dissolved in triethanolamine[2]	175	S	S	S	S	S	S	S	S	S	—	—	—	—

[1]Concentrations are all on a molar basis. The range is from 0.000029 M (No. 1) to 0.122000 M (No. 13). Each succeeding concentration is double the one preceding it. The letter "I" indicates inferiority of the chemical as compared to 2,4-D and the letter "S" indicates superiority, "E" indicates no difference. A single asterisk (*) indicates significance at the .05 level and a double asterisk (**) at the .01 level.

[2]Compounds prepared in the Chemistry Dept., Colorado Agricultural Experiment Station.
[3]Ciba Pharmaceutical Products Company.
[4]Sherwin Williams Company.
[5]Abbott Laboratories.
[6]United States Vanadium Corporation.
[7]Cutter Laboratories.
[8]Parke, Davis and Company.
[9]Eastman Kodak Company.
[10]Dow Chemical Company.
[11]Rohm and Haas Company.
[12]U. S. Rubber Company.
[13]E. I. Dupont de Nemours and Company.
[14]Schuykill Chemical Company.
[15]Paragon Testing Laboratories.
[16]Schering Corporation.
[17]Norden Laboratories.

TABLE 5.—*Chemicals with significantly superior growth-regulating properties in the high concentrations of the pea test.*

Chemical	Chem. No.	Concentrations[1]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Acetyl acetone[9]	197	**I	**I	**I	**I	**I	*I	**I	*I	I	*S	S	*S	**S
Beta-(beta-naphthyloxy) propionic acid[2]	168	**I	**I	**I	**I	**I	I	I	S	*S	*S	S	S	S
P-chlorophenoxyacetic acid dissolved in triethanolamine[2]	166	*S	S	S	I	I	I	**S	*S	S	**S	S	S	S
Di-(2,4-dichlorophenoxy) acetic acid[2]	61–2	I	**S	S	S	S	I	I	—	*S	S	*S	**S	**S
Diethylstilbesterol[17]	137	*I	*I	**I	**I	**I	**I	*I	**I	*I	S	S	**S	**S
2,4-dimethylphenoxychloroacetic acid[2]	123	S	S	I	*I	I	I	**S	*S	S	S	S	**S	S
1,4-dimethylphenoxychloroacetic acid[2]	122	**I	**I	**I	**I	**I	*I	I	S	S	**S	*S	I	*S
3,5-dimethylphenoxychloroacetic acid[2]	120	**I	**I	**I	**I	I	I	I	—	I	*S	*S	—	*S
Glucose	211	**I	I	I	**I	**I	I	**I	S	I	**S	**S	**S	S
Meta-(2,4-dichlorophenoxy) benzoic acid[2]	180	**I	**I	**I	**I	**I	**I	*I	I	I	I	I	**S	*S
Perandren[3]	192	**I	**I	**I	**I	*I	**I	**I	**I	I	I	S	S	*S
Zincdimethyldithiocarbamate[13]	186	I	I	*I	S	*I	S	*S	I	**S	**S	**S	**S	**S

[1]See Table 4 for footnotes.

TABLE 6.—*Chemicals with significantly superior growth-regulating properties in the middle concentrations of the pea test.*

Chemical	Chem. No.	Concentrations[1]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Alpha-(2-chlorophenoxy) propionic acid[2]	161	**I	**I	**I	**I	**I	*I	S	**S	*S	I	I	*I	*I
Alpha-(2,4,5-trichlorophenoxy) propionic acid[2]	160	—	S	*S	**S	*S	S	*S	**S	**S	*S	S	S	I
Alpha-(phenoxy)propionic acid[2]	97	**I	I	S	I	**S	**S	**S	**S	**S	I	S	S	S
Di-(2,4,5-trichlorophenoxy) acetic acid[2]	72	S	I	I	*S	**S	**S	**S	**S	**S	S	S	I	*S
2-amino-5-azoanisole[9]	201	I	*S	S	**I	I	S	**S	S	**S	S	S	S	I
Indole-3-acetic acid[9]	143	I	*I	**I	S	I	I	**S	—	**I	*I	—	I	I
2-methylphenoxyacetic acid dissolved in triethanolamine[2]	174	*I	**I	**I	**I	**I	I	**S	*S	**S	S	I	I	I
Proliferol[14]	210	I	**I	*S	**I	E	**I	I	**I	**S	S	S	S	*S
Pyridine[15]	156	I	I	S	S	S	S	*S	**S	I	**I	**I	**I	**I

[1]See Table 4 for footnotes.

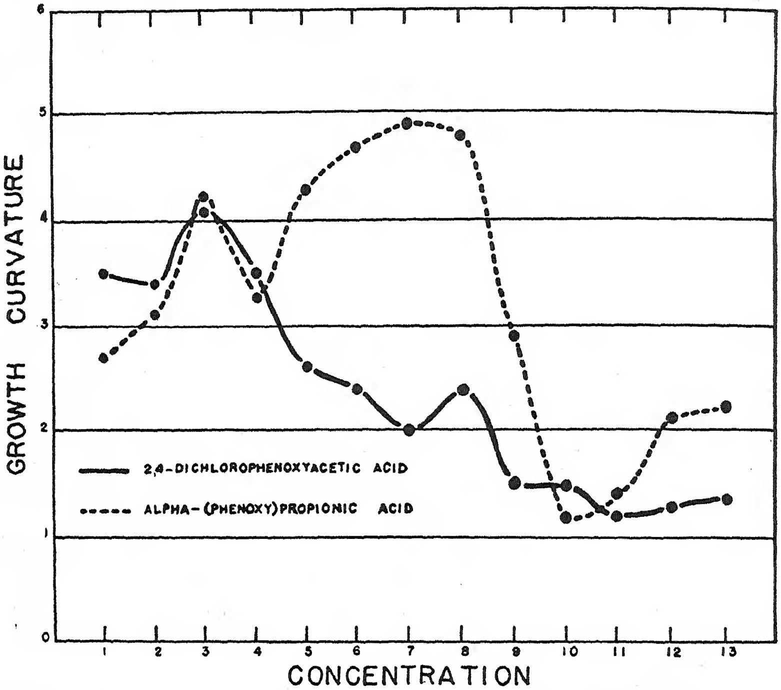

FIG. 6.—Pea stem growth curves of alpha-(phenoxy)propionic acid and of 2,4-dichlorophenoxyacetic acid.

TABLE 7.—*Chemicals with significantly superior growth-regulating properties in the lower concentrations of the pea test.*

Chemical	Chem. No.	Concentrations[1]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
4-chlorophenoxyacetic acid[2]	154	S *	S *	** S **	S **	S **	S *	** S *	I	I	I	S	I	— *
1,1,1-trichloro-2,2-bis-(p-chlorophenyl) ethane[2]	1	S **	S **	S **	S **	S	S	S	S	I	I *	S	S	S
Gamma-(indole-3)-n-butyric acid[9]	194	S **	S **	S **	S **	I **	I **	I **	S	S	S *	S	S	I
3,4-dimethylphenoxychloroacetic acid[2]	121	S **	S **	S **	S *	S **	S	S *	S *	S	S	S	S	I
3-methylphenoxyacetic acid[2]	59	I **	I **	S **	S	S *	I	I	I *	I	I	I *	—	I
1-nitroso-2-naphthol[9]	202	S	S	S	S	S	S	S	I	I	—	S	S	I

[1]See Table 4 for footnotes.

All data covering the greenhouse castor bean tests are summarized in Table 11. Chemicals are arranged in order of decreasing reaction as compared to 2,4-D.

From an inspection of the results shown by the castor bean tests

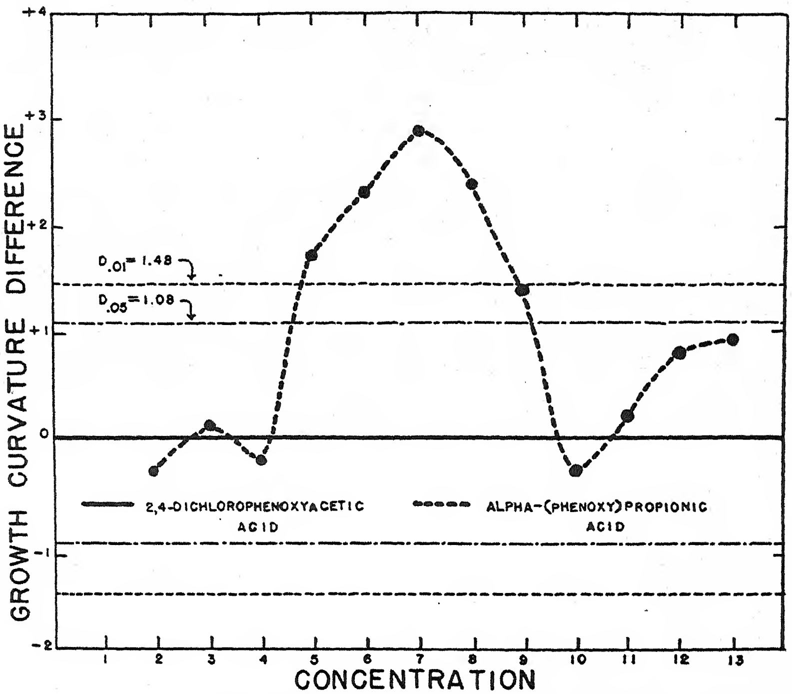

FIG. 7.—Criteria of significance of the growth curve differences between alpha-(phenoxy)propionic acid and of 2,4-dichlorophenoxyacetic acid as shown in Fig. 6.

TABLE 8.—*Chemicals with an F value not significant and reactions not different from 2,4-D.*

Chemical[1]	Chemical No.
2-chloro-4-nitroacetic acid[2]	182
3,4-dimethyl-4-nitroacetic acid[2]	117
Disodium ethylene bisdithiocarbamate[11]	187
Ethyl carbamate in triethanolamine[2]	185
Meta-(2,4-dichlorophenoxy)-anthranilic acid[6]	181
Progynon DH[16]	140
2,4,5-trichlorophenoxyacetic acid[10]	33

[1]See Table 4 for footnotes

(Table 11) and of the same compounds tested by the pea test (Tables 4 to 10), there appears to be a fairly close correspondence. Of the 26 compounds tested on castor bean plants, all but 5 showed results in accord with what would have been expected from the pea test. These five compounds were alpha-(2,4,5-trichlorophenoxy) propionic acid (No. 161), phenetole (No. 157), 3,4-dimethylphenoxychloroacetic acid (No. 121), 2,4-dichlorophenoxyacetic acid dissolved in triethanolamine (No. 153), and pyridine (No. 156). Compounds Nos. 121, 153, 156, and 157 were superior to 2,4-D in the pea test but inferior in the

TABLE 9.—*Chemicals with significantly inferior growth-regulating properties in the lower concentrations of the pea test.*

Chemical	Chem. No.	Concentrations[1]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Alpha-benzoin oxime[9]	198	**I	**I	**I	**I	**I	**I	S	I	S	S	I	S	I
Alpha-(2-chlorophenoxy)-propionic acid[2]	165	**I	**I	**I	**I	**I	**I	**I	I	S	**S	I	S	I
2,4,5-trichlorophenoxy-chloroacetic acid[2]	71	**I	**I	**I	**I	**I	*I	*S	S	I	S	S	S	S
1,8-dihydroxynaphthalene 3,6-disulfonic acid[9]	195	**I	**I	**I	**I	**I	**I	**S	S	S	*S	I	**I	**I
Lutocylin[3]	188	**I	**I	**I	**I	**I	**I	**I	I	S	S	S	I	S
3,5-dimethylacetic acid[2]	116	**I	**I	**I	**I	**I	**I	**I	**I	I	*S	I	*I	**S
Trimethyleneglycol in triethanolamine[9]	169	**I	**I	**I	I	**I	**I	**I	I	**I	*S	S	S	S
P-nitrophenylacetic acid[9]	196	**I	**I	**I	**I	**I	*I	I	S	S	S	S	S	I
Phenetole in triethanolamine[9]	170	**I	**I	**I	**I	**I	**I	**I	S	S	*S	S	S	*I

[1]See Table 4 for footnotes.

castor bean test. The compound 161 was significantly inferior in the pea test at the lower six concentrations but superior or equal to 2,4-D in all concentrations of the castor bean test. These results suggest that where it is desirable to test a large number of compounds for herbicidal properties similar to 2,4-D, the pea test can be used to eliminate a large percentage of the compounds. Some compounds of desirable character are sure to be missed if only the pea test is used. Perhaps a good procedure would be to select compounds first by the pea test, and then to test the remainder by the castor bean test. A limited number of the most promising compounds from each test could then be used for adequately replicated field tests on deep-rooted perennials with the best chances of success.

The results of the pea tests show a few other interesting and perhaps significant trends. The desirability of comparing different chemicals for their growth-regulating properties over a wide concentration range was emphasized in all cases where some concentrations were significantly superior and others were significantly inferior. For instance, 3-methylphenoxyacetic acid (No. 159, Table 7) produced significantly inferior reactions at concentration No. 8 (0.003812 M) and yet at concentrations 3, 4, and 5 (0.000119 M to 0.000476 M) produced reactions significantly superior to 2,4-D. If this compound had been tested at only concentration No. 8, it would have been discarded. These results substantiate the work of Horsfall[6]

[6]HORSFALL, JAMES O., Quantitative bioassay of fungicides in the laboratory. Bot. Rev., 11:357–391. 1947.

TABLE 10.—*Chemicals with significantly inferior growth-regulating properties in most concentrations of the pea test.*

Chemical	Chem. No.	Concentrations[1]												
		1	2	3	4	5	6	7	8	9	10	11	12	13
		**	**	**	**	**	**	*	**			**	**	
△ [4] androstenedione-3,17[3]	191	I	I	I	I	I	I	I	I	S	I	I	I	—
				*	**	**	**	**				**	**	
Butyl ester of 2,4-dichlorophenoxyacetic acid[4]	150	I	I	I	I	I	I	I	I	I	I	I	I	I
			**	*	**	**	**				**			
Di-(2,4-dichlorophenoxy) acetic acid[2]	173	I	I	I	I	I	I	I	I	S	S	—	—	—
			**	*	**	**	**	*		**				
Di-(2,4,5-trichlorophenoxy) acetic acid dissolved in triethanolamine[2]	172	I	I	I	I	I	I	I	I	I	I	—	—	—
		**	**	**	**	**	**	*			**	**	*	
Diovacylin	190	I	I	I	I	I	I	I	I	S	I	I	I	S
		**	**	**	**	**	**	**	**	**	**	**	**	**
Estriol[5]	144	I	I	I	I	I	I	I	I	I	I	I	I	I
		**	**	*	**				**	*				*
Estrone[5]	142	I	I	I	I	S	S	I	I	I	I	I	I	I
		**	**	**	**	**	**	**	**	**				
Ethylchloroacetal[6]	111	I	I	I	I	I	I	I	I	I	I	I	—	I
		**	**	**	**	**	*							
Ethyl ester of 2,4-dichlorophenoxy-acetic acid[4]	151	I	I	I	I	I	I	I	S	S	I	—	—	—
		**	**		**	**	*	**	**	**	**	**	**	
D-galactose[7]	212	I	I	I	I	I	I	I	I	I	I	I	I	I
		**	**	**	**	**	**	**	**	**	**	**	**	**
Gonadin serum[7]	135	I	I	I	I	I	I	I	I	I	I	I	I	I
		*	**	**	**	**	**		*	**	**	**	**	**
Methyl ester of alpha-naphthyleneacetic acid[10]	206	I	I	I	I	I	I	I	I	I	I	I	I	I
		*	**	**	*		**	*						
2-methylphenoxyacetic acid[2]	58	I	I	I	I	—	I	I	I	S	—	—	—	—
		**	**	**	**	**	**							
Metandren[3]	189	I	I	I	I	I	I	I	I	I	I	S	I	I
		**	**	**	**	*	**	**	**					
P-phenylenediamine[9]	203	I	I	I	I	I	I	I	I	I	I	I	I	S
		**	**	**			*		*	**	*	**	**	**
Salicylic acid chloralide[2]	26	I	I	I	I	I	I	I	I	I	I	I	I	I
		**	**	**	**	**	**			*				
Sodium styrene sulfonate[2]	207	I	I	I	I	I	I	I	I	I	S	S	—	I
		**	**	**	**	**	**	**	**	**	**	**	**	**
Theelol[8]	145	I	I	I	I	I	I	I	I	I	I	I	I	I
		**	**	**	**	**	**	**		**		*	*	*
Triethanolamine[9]	171	I	I	I	I	I	I	I	I	I	I	I	I	I
		**	**	**	**	**	**	**	**	**	**	**		
Zinc ethylene bis-dithio-carbamate[11]	205	I	I	I	I	I	I	I	I	I	I	I	I	S

[1]See Table 4 for footnotes.

who has demonstrated the advantages of testing fungicides over a concentration range by the technique of dosage response.

Included in the list of compounds studied in the pea test were 10 animal sex-hormones. Of these perandren (No. 192) and progynon DH (No. 140) were the only ones with growth-regulating properties equal to or superior to 2,4-D at any concentration.

The two organic fungicides, zinc dimethyldithiocarbanate (No. 1-6) trade name of Zerlate, and disodium ethylene bisdithiocarbamate (No. 187), trade name of Dithane, gave interesting pea test responses. Zerlate (No. 186) was significantly superior to 2,4-D at the

TABLE 11.—*Castor bean plant reactions of a selected group of chemicals, arranged according to their decreasing activity in relation to 2,4-D.*

Chemical	Chem. No.	Concentration												
		1	2	3	4	5	6	7	8	9	10	11	12	13
4-chlorophenoxyacetic acid	154	*S		S		S		S		S		E		E
Alpha-(2-chlorophenoxy) propionic acid	161	S		S		S		S		S		E		E
Alpha-(phenoxy) proponic acid	97	I		I		I		S		S		S		S
P-chlorophenoxyacetic acid dissolved in triethanolamine	175	I		I		I		S		S		S		S
Di-(2,4-dichlorophenoxy) acetic acid	173	I		I		I		S		S		S		S
Alpha-(2-chlorophenoxy) propionic acid	165	I		I		I		S		S		E		E
Gamma-(indole-3)-n-butyric acid	194	I		I		I		E		E		S		S
2,4,5-trichlorophenoxychloroacetic acid	71	I		I		I		I		S		S		S
Di-(2,4,5-trichlorophenoxy) acetic acid	72	I		I		I		I		E		S		S
Sodium salt of 2,4-dichlorophenoxyacetic acid, monohydrate	147			S	E	E	E	E	E	E	I	I	I	I
Ammonium salt of 2,4-dichlorophenoxyacetic acid	149			E	E	E	E	E	E	E	I	I	I	I
Butyl ester of 2,4-dichlorophenoxyacetic acid	150			E	I	I	I	E	E	E	I	E	I	I
1,1,1-trichloro-2,2-bis-(p-chlorophenyl) ethane	1	I		I		I		I		I		I		S
Ethyl ester of 2,4-dichlorophenoxyacetic acid	151			S	I	I	I	I	I	I	I	I	I	I
2,4-dichlorophenoxyacetic acid dissolved in triethanolamine	153			E	I	I	I	I	I	E	I	E	I	I
P-chlorophenoxyacetic acid dissolved in triethanolamine	166	I		I		I		E		I		I		E
M-(2,4-dichlorophenoxy) benzoic acid	180	I		I		I		I		I		I		I
Phenetole	157	E		I		I		I		I		I		I
3,4-dimethyl-4-nitroacetic acid	117	I		I		I		I		I		I		I
Trimethylene glycol	155	I		I		I		I		I		I		I
Pyridine	156	I		I		I		I		I		I		I
Di-(2,4,5-trichlorophenoxy)acetic acid dissolved in triethanolamine	172	I		I		I		I		I		I		I
3,4-dimethylphenoxychloroacetic acid	121	I		I		I		I		I		I		I
2-methylphenoxyacetic acid dissolved in triethanolamine	174	I		I		I		I		I		I		I
Trimethylene glycol in triethanolamine	169	I		I		I		I		I		I		I
2,4-dimethylphenoxychloroacetic acid	123	I		I		I		I		I		I		I

*All comparisons made on the basis of reaction in relation to 2,4-D. S =Superior; E =Equal to; and I =Inferior.

five highest concentrations and Dithane (No. 187) was not significantly different.

The insecticide 1-trichloro-2,2-bis(p-chlorophenyl) ethane or DDT was superior to 2,4-D in all but two concentrations and significantly superior at concentration No. 8.

SUMMARY

The growth-regulating properties of 74 chemicals were investigated by a modification of Went's pea test. Results were statistically analysed and classified, using the reaction of 2,4-D as the standard.

A quantitative herbicidal test on castor bean plants is described and illustrated.

A group of 26 chemicals, selected from the pea test, were studied for their herbicidal action using the castor bean test. Chemicals were arranged according to their decreasing activity.

A procedure for selecting organic compounds with herbicidal properties similar to 2,4-D was suggested. This involved the use of both the pea test and the castor bean test.

The value of comparing the growth-regulating and herbicidal properties of chemicals on a molar basis was emphasized.

The weakness of comparing chemicals at a single concentration was pointed out, and the advantages of making comparisons over a wide concentration range were shown.

The Influence of Domestic Ryegrass and Redtop Upon the Growth of Kentucky Bluegrass and Chewing's Fescue in Lawn and Turf Mixtures[1]

Milton H. Erdmann and C. M. Harrison[2]

THE inclusion of large percentages of so-called "nurse grasses" in lawn seed mixtures is a common practice. Grasses such as domestic ryegrass and redtop have an advantage over the desired turf grasses in that they are quicker starting; thus producing green cover sooner, reducing the time that the soil is left bare, and cutting down on possible erosion. However, these "nurse grasses" inhibit the growth of the desired grasses and once past the seedling stage have the disadvantage of being coarse and rough; they do not produce the fine, even turf which is desired.

In an ideal mixture, the "nurse grass" should get an early start, not be unduly competitive, and should disappear entirely after one season's time, allowing the desired grass to dominate at an early stage. In practice, however, the "nurse grass" dominates for the first season and very often persists for several seasons. Thus, several years are necessary to establish a turf which is free of coarse grasses. It is therefore frequently advisable to use a pure species or a mixture of desired grasses and to omit the faster growing, coarse nurse grasses from the mixture. If a "nurse grass" is to be used, the percentage in the seed mixture should be at a minimum which will produce an initial cover but yet not unduly retard the growth of the desired grass or grasses.

In order to secure more specific information on the competitive effects of the "nurse" grasses, an experiment was set up in a greenhouse, maintained at approximately 70°F, at Michigan State college in the winter of 1946 which was designed to study the effect of two common nurse grasses on the establishment and growth of two common turf grasses. The rate of seeding alone and in mixture and any inhibiting effect which one grass had upon another were studied and observed.

REVIEW OF LITERATURE

The initial rapidity of seedling development of Italian ryegrass was observed by Davies and Thomas (4)[3] when working with pure species seedings of grasses. Findlay (5) reported that meadow fescue would not compete against ryegrass the first year, and that the quantity of orchard grass and timothy in both hay and pasture was increased by reducing the quantity of perennial ryegrass. Bell and Tedrow (2), in their studies of turf under airport conditions, found that creeping red fescue did not compete with perennial ryegrass even where well

[1]Joint contribution from the Section of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, cooperating. Jour. article No. 863 new series, of the Michigan Agricultural Experiment Station. Part of a thesis submitted by the senior author at Michigan State College in partial fulfillment of the requirements for the degree of master of science. Received for publication March 11, 1947.

[2]Graduate Assistant and Professor in Farm Crops, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 689.

adapted. They recommended that ryegrass should be omitted from the seed mixture or used only in small quantities so as to insure a good stand of the permanent perennial grasses desired. Van Dersal (8) also recommended that the use of perennial ryegrass in turf mixtures be discontinued. Davies (3) found that perennial ryegrass exerts a strong depressing effect on the field establishment of bulb canarygrass.

In 1898 Beal (1) observed that none of the commercial lawn seed mixtures on the market produced as fine and permament a lawn as a few of the best grasses used separately. Lapp (6) observed from his study of 20 lawn mixtures that the turf quality was higher and the colonizing ability stronger when the percentage of the perennial species was larger. Morgenweck (7) found that desired species can better compete when their rate of seeding is increased in relation to that of the nurse grass. He also noted that low seeding rates produced the same yield as higher seeding rates because of reduced competition.

Findlay (5) reported that there was no direct relationship between the weight of hay produced and the quantity of perennial ryegrass sown.

EXPERIMENTAL PROCEDURE

Four grasses were selected and used in various combinations and at different rates of seeding. Kentucky bluegrass, *Poa pratensis*, and Chewing's fescue, *Festuca rubra*, var. *commutata*, were selected as representative of turf grass and sown with domestic ryegrass, *Lolium multiflorum* and *perenne*, and redtop, *Agrostis alba*, as nurse grasses. The seed was planted on February 28 in quartz sand cultures in 10-inch clay pots. Twenty-two mixtures were used, variations being made by using combinations at rates of seeding from 10 to 40 pounds per acre. In addition to the 22 mixtures, each of the four grasses used was sown alone to serve as a check.

Each mixture, and the pure species, was replicated five times, making a total of 130 pots. After sowing, the grasses were watered regularly and were given a complete nutrient solution once a week during the period of the experiment.

Beginning on April 16, the grasses from three pots of each culture were harvested. The sand was washed from the roots and the species in each mixture were separated. Roots and tops were weighed separately, both green and after being oven-dried, but only total dry weights of roots and tops are herein recorded. The grasses in the remaining two pots of the original five were harvested in a similar manner between May 16 and May 23.

EXPERIMENTAL RESULTS

Table 1 shows the results, on a dry-weight basis, from three pots of each mixture. This harvest extended over a 3-week period because of the time required to separate species within a mixture. Therefore the date of harvest must be taken into consideration when comparing weights of grasses harvested from different mixtures.

It will be noted in Fig. 1 that of the grasses sown alone, domestic ryegrass made the greatest growth in the slightly more than 6 weeks between the planting of the seed and harvest. Redtop did not make as much growth as domestic ryegrass, but it more than doubled that of the Kentucky bluegrass and outyielded the Chewing's fescue by a considerable amount. Thus, on the basis of pure stands alone, domestic ryegrass and redtop show their characteristic quick growth.

By comparing the growth of individual grasses alone and in mixture it was found that domestic ryegrass inhibited the growth of all other grasses, including redtop. Redtop inhibited the growth of Kentucky bluegrass and Chewing's fescue, but not to the same extent as domestic ryegrass. Fig. 2 illustrates the overshadowing of Kentucky bluegrass and Chewing's fescue by ryegrass and redtop. Domestic ryegrass and redtop definitely dominated in mixtures in which they made up 20% or more by weight of the seed planted.

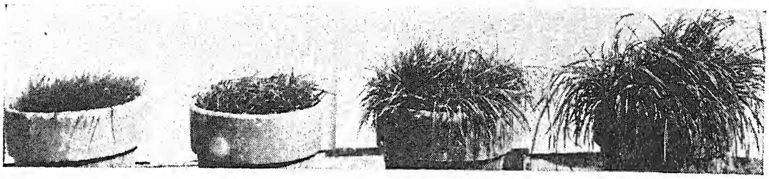

FIG. 1.—Growth of pure species on April 15th. Left to right: Chewing's fescue, Kentucky bluegrass, redtop, and domestic ryegrass. All seeded at 20 pounds per acre. Note the coarser, heavier growth of domestic ryegrass and redtop compared to that of Chewing's fescue and Kentucky bluegrass.

FIG. 2.—Growth of pure species compared with mixtures on April 15th. Left to right: Chewing's fescue at 20 pounds per acre; mixture of redtop at 10 pounds, Kentucky bluegrass at 5 pounds, and Chewing's fescue at 5 pounds per acre; Kentucky bluegrass at 20 pounds per acre; mixture of domestic ryegrass at 10 pounds, Kentucky bluegrass at 5 pounds, and Chewing's fescue at 5 pounds per acre. Note that domestic ryegrass and redtop dominate in the mixtures.

Kentucky bluegrass and Chewing's fescue were about equal to each other in rate of growth; neither consistently outweighed the other in comparative mixtures or when sown alone.

At the time of planting, a count was made of the number of seeds planted for each species at the different rates of seeding. It was found that 305 redtop, 106 Kentucky bluegrass, 31 Chewing's fescue, or 13 domestic ryegrass seeds per pot were equivalent to a seeding rate of 5 pounds per acre each.

A count was made later of the plants in one pot seeded with a mixture of 5 pounds of Kentucky bluegrass, 5 pounds of Chewing's fescue, and 10 pounds of domestic ryegrass per acre. There were 38 Kentucky bluegrass plants, 25 Chewing's fescue plants, and only 24 domestic ryegrass plants; yet the green weight in grams of the Kentucky bluegrass plants was only 6.0, of the Chewing's fescue 5.25, and of the domestic ryegrass 231.5.

The dry weights of the grasses harvested from the remaining cultures, the eleventh week after planting are recorded in Table 2 as the mean weights for two pots. Results in the second harvest were substantially the same as those obtained in the first.

However, one difference noted in the results obtained from the two harvests was a change in the ratio of the weights of the grasses harvested from the pure species cultures. Compared to the weights at the first harvest, Kentucky bluegrass made the greatest gain in weight between the time of the first and second harvest, Chewing's

fescue and redtop made the next greatest gains, and domestic ryegrass made the least gain of the four grasses. The average weight of the Kentucky bluegrass tops and roots in each pot increased about eight times, the Chewing's fescue and redtop each increased about five times, and the domestic ryegrass increased slightly less than four times in weight in the month between harvests. However, the average weight of the tops and roots of the domestic ryegrass per pot at the second harvest was more than twice the weight of either the Kentucky bluegrass or Chewing's fescue, and the average weight of the redtop in each pot at the second harvest was considerably greater than that of either the Kentucky bluegrass or Chewing's fescue. Comparing

TABLE 1.—*The yields of tops and roots in grams of dry matter, average of three pots.*

Mixture and rate of seeding in pounds per acre*	Domestic ryegrass	Redtop	Ky. bluegrass	Chewing's fescue	Total	Date of harvest
Ryegrass, 20 lbs.	25.33	—	—	—	25.33	Apr. 16
Redtop, 20 lbs.	—	15.50	—	—	15.50	16
Bluegrass, 20 lbs.	—	—	5.66	—	5.66	17
Fescue, 20 lbs.	—	—	—	9.00	9.00	17
Bluegrass, 5 lbs.; fescue, 5 lbs.	—	—	7.40	5.35	12.75	Apr. 30
Bluegrass, 10 lbs.; fescue, 10 lbs.	—	—	6.20	6.80	13.00	24
Ryegrass, 5 lbs.; redtop, 5 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	17.00	6.83	0.65	1.02	25.50	Apr. 19
Ryegrass, 10 lbs.; redtop, 10 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	53.00	7.80	2.25	3.82	66.87	May 5
Ryegrass, 10 lbs.; redtop, 10 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	44.30	11.50	1.23	0.85	57.88	5
Ryegrass, 5 lbs.; redtop, 5 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	43.80	5.00	1.08	1.74	51.62	6
Ryegrass, 5 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	44.50	—	2.12	1.80	48.42	May 1
Ryegrass, 10 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	50.50	—	4.00	2.80	57.30	6
Ryegrass, 10 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	30.80	—	0.56	0.57	31.93	Apr. 22
Ryegrass, 5 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	30.80	—	1.90	1.90	34.60	26
Ryegrass, 5 lbs.; bluegrass, 10 lbs.	46.00	—	8.42	—	54.42	May 6
Ryegrass, 5 lbs.; fescue, 10 lbs.	37.70	—	—	4.00	41.70	7
Ryegrass, 5 lbs.; bluegrass, 20 lbs.	34.00	—	10.20	—	44.20	8
Ryegrass, 5 lbs.; fescue, 20 lbs.	54.80	—	—	16.00	70.80	9
Redtop, 5 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	—	20.25	4.00	3.90	28.40	May 1
Redtop, 10 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	—	37.30	3.42	4.90	45.62	6
Redtop, 10 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	—	23.25	1.18	0.80	25.23	Apr. 22
Redtop, 5 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	—	9.20	4.42	4.55	18.17	29
Redtop, 5 lbs.; bluegrass, 10 lbs.	—	24.20	7.30	—	31.50	May 7
Redtop, 5 lbs.; fescue, 10 lbs.	—	32.20	—	9.70	41.90	7
Redtop, 5 lbs.; bluegrass, 20 lbs.	—	25.70	17.80	—	43.50	8
Redtop, 5 lbs.; fescue, 20 lbs.	—	24.80	—	14.50	39.30	9

*Domestic ryegrass, redtop, Kentucky bluegrass, and Chewing's fescue. All mixtures planted Feb. 28.

gains made between harvests on the basis of grams gained per pot, domestic ryegrass made the greatest gain, followed by redtop, Kentucky bluegrass, and Chewing's fescue. The gains made by domestic ryegrass and redtop were relatively high when compared to those made by Kentucky blue grass or Chewing's fescue.

TABLE 2.—*The yields of tops and roots in grams of dry matter, average of two pots.*

Mixture and rate of seeding in pounds per acre*	Domestic ryegrass	Redtop	Ky. bluegrass	Chewing's fescue	Total	Date of harvest
Rye, grass, 20 lbs.	90.20	—	—	—	90.20	May 16
Redtop, 20 lbs.	—	71.20	—	—	71.20	16
Bluegrass, 20 lbs.	—	—	42.50	—	42.50	16
Fescue, 20 lbs.	—	—	—	40.20	40.20	16
Bluegrass, 5 lbs.; fescue, 5 lbs.	—	—	27.50	10.00	37.50	May 17
Bluegrass, 10 lbs.; fescue, 10 lbs.	—	—	21.20	22.10	43.30	20
Ryegrass, 5 lbs.; redtop, 5 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	76.70	14.50	2.00	2.60	95.80	May 17
Ryegrass, 10 lbs.; redtop, 10 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	91.70	31.00	3.00	3.70	129.40	19
Ryegrass, 10 lbs.; redtop, 10 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	76.70	26.70	1.20	0.80	105.40	18
Ryegrass, 5 lbs.; redtop, 5 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	70.20	6.60	4.50	4.70	86.00	20
Ryegrass, 5 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	80.00	—	2.80	2.00	84.80	May 17
Ryegrass, 10 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	108.70	—	2.10	2.30	113.10	19
Ryegrass, 10 lbs.; bluegrass, 5 lbs.. fescue, 5 lbs.	90.00	—	1.70	1.00	92.70	19
Ryegrass, 5 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	78.20	—	7.70	6.00	91.90	20
Ryegrass, 5 lbs.; bluegrass, 10 lbs.	68.50	—	20.20	—	88.70	May 21
Ryegrass, 5 lbs.; fescue, 10 lbs.	78.20	—	—	4.10	82.30	22
Ryegrass, 5 lbs.; bluegrass, 20 lbs.	63.70	—	23.20	—	86.90	23
Ryegrass, 5 lbs.; fescue, 20 lbs.	75.20	—	—	7.00	82.20	23
Redtop, 5 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	—	18.50	10.00	6.20	34.70	May 17
Redtop, 10 lbs.; bluegrass 10 lbs.; fescue, 10 lbs.	—	63.50	9.50	8.50	81.50	20
Redtop, 10 lbs.; bluegrass, 5 lbs.; fescue, 5 lbs.	—	89.70	2.50	1.90	94.10	19
Redtop, 5 lbs.; bluegrass, 10 lbs.; fescue, 10 lbs.	—	15.00	24.20	12.70	51.90	20
Redtop, 5 lbs.; bluegrass, 10 lbs.	—	19.70	29.20	—	48.90	May 21
Redtop, 5 lbs.; fescue, 10 lbs.	—	44.00	—	9.20	53.20	22
Redtop, 5 lbs.; bluegrass, 20 lbs.	—	51.00	16.50	—	67.50	23
Redtop, 5 lbs.; fescue, 20 lbs.	—	54.50	—	17.50	72.00	23

*Domestic ryegrass, redtop, Kentucky bluegrass, and Chewing's fescue. All mixtures planted Feb. 28.

Doubling the rate of seeding of Chewing's fescue in mixtures consistently increased the weights of the tops and roots harvested. Doubling the rate of seeding of Kentucky bluegrass in mixtures produced inconsistent results.

In both harvests, the average weight of the tops and roots from the

pots seeded with a mixture consisting of 5 pounds per acre each of domestic ryegrass, redtop, Kentucky bluegrass, and Chewing's fescue was almost the same as that harvested from the pots seeded with domestic ryegrass at 20 pounds per acre.

Table 2 shows that sowing a mixture containing Kentucky bluegrass and Chewing's fescue at 10 pounds each produced almost the same amount of top and root growth as either grass sown alone at 20 pounds per acre.

A mixture of all four grasses sown at 10 pounds each per acre (Table 2) produced only about 30% more tops and roots than a mixture of all four grasses sown at 5 pounds each.

Increasing domestic ryegrass from 5 to 10 pounds per acre (Table 2) increased the total weight harvested only slightly when sown alone or in mixture with Kentucky bluegrass and Chewing's fescue. Increasing redtop from 5 to 10 pounds per acre when sown alone or in mixture with Kentucky bluegrass and Chewing's fescue, increased the total weight harvested considerably.

Increasing the rate of seeding of domestic ryegrass, Kentucky bluegrass, and Chewing's fescue in a mixture from 5 to 10 pounds each increased the harvest about 37%. Increasing the rate of seeding of redtop, Kentucky bluegrass, and Chewing's fescue in a mixture from 5 to 10 pounds each increased the weight of the tops and roots harvested over 100%.

There was some variation in the amount of roots harvested, the fescue roots making up about one-fourth of the total weight of the plant; the roots of domestic ryegrass, Kentucky bluegrass, and redtop plants being about two-sevenths the total weight of the plant.

Domestic ryegrass plants were coarse and rough during thier entire period of growth. Redtop plants were fine textured during their early growth but became coarse in a few weeks time.

DISCUSSION

The growth of either Kentucky bluegrass or Chewing's fescue was definitely inhibited in this experiment when sown in mixture with either domestic ryegrass or redtop. Several workers have noted the strong dominance of ryegrass over various turf and pasture grasses, but the literature does not report any such dominance by redtop as found in this experiment.

As the experiment was set up, domestic ryegrass or redtop did not make up less than 20% by weight of the seed in any mixture in which they were included.

Results showed that increasing or decreasing the rate of seeding of domestic ryegrass had little effect upon the weight of tops and roots harvested. Therefore reducing the amount of domestic ryegrass in the seed mixture within the range of this experiment did not reduce its dominance proportionately. The results with redtop indicate that a lowering of the percentage of seed in the mixture would be of help in reducing dominance.

The dominance of domestic ryegrass and redtop over Kentucky bluegrass and Chewing's fescue seems to be largely due to more rapid initial growth. In pure culture, either domestic ryegrass or redtop had

a thick, heavy growth 6 weeks after seeding; on the same date Kentucky bluegrass and Chewing's fescue had only light to medium growth and thickness. Fig. 1 shows the relative growth of the pure grasses at 6 weeks and Fig. 2 the growth of the pure species in comparison with the mixtures.

Although the ratio of the weights of domestic ryegrass and redtop to the weights of Kentucky bluegrass and Chewing's fescue was reduced for the pure seedings from the first to the second harvest, the weight ratio of these grasses to each other when in mixture remained approximately the same. Thus the initial dominance of domestic ryegrass and redtop over Kentucky bluegrass and Chewing's fescue was not diminished within the time limits of this experiment.

When comparing the production of the four species, no relationship was found between the number of seeds sown and plant production. For a given rate of seeding, domestic ryegrass had the smallest number of seeds but the greatest production; redtop had the greatest number of seed and was second in production. Although about equal in production, Kentucky bluegrass had over three times the number of seeds as Chewing's fescue per unit of weight.

The experimental results indicate that, of the four grasses, Kentucky bluegrass and Chewing's fescue could grow best together and with the least competition. Neither of these grasses was consistently dominant over the other. Although the two grasses did not compete with each other, they did not produce any better turf or increase production when in a mixture than did either of the grasses when sown alone. Showing similar results, the mixture of the four grasses sown at 5 pounds each produced only as much as the ryegrass sown alone at 20 pounds per acre.

The data from the two harvests indicate that the finer grasses, when in pure culture, make a slow growth in the initial period but tend to make up this difference after the seedling phase has passed. This same tendency does not seem to hold true when the turf grasses are sown in mixture with the nurse grasses.

Consequently, it would seem advisable to recommend pure seedings of the one desired turf grass on areas where a fast-growing nurse grass was not essential in establishing quick cover. Field trials[4] with mixtures indicate that the desired grasses do not completely dominate the mixture from one to three years after seeding, and in some cases the coarser grasses, after disappearing from the turf, leave bare spaces in the turf for a considerable period. The final establishment of complete cover of a given turf grass was accomplished much sooner when sown in pure species than when sown at the same or heavier rates in mixture with the quicker growing, more competitive nurse grasses. The data from the present experiment seem to agree with these observations and to point out that mixtures containing the quicker starting, more aggressive grasses have only one desirable point in their favor, namely, that of quicker ground cover. Once this quick cover is accomplished, the coarser grasses react unfavorably in the establishment of a desired turf.

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[4]Unpublished data from the Farm Crops Department, Michigan State College.

CONCLUSIONS

1. In pure cultures, either domestic ryegrass or redtop made much greater growth than Kentucky bluegrass or Chewing's fescue. Domestic ryegrass produced the greatest growth of the four grasses.
2. In mixtures, both domestic ryegrass and redtop inhibited the growth of Kentucky bluegrass and Chewing's fescue.
3. Domestic ryegrass and redtop dominated in mixtures in which they made up 20% or more of the weight of seed planted.
4. The dominance of domestic ryegrass and redtop over Kentucky bluegrass and Chewing's fescue did not diminish with time.
5. Kentucky bluegrass and Chewing's fescue did not compete with each other, but neither did their production increase when in mixture together.
6. Increasing, or decreasing, the rate of seeding of domestic ryegrass had little effect upon the weight of the tops and roots harvested.
7. Increasing the rate of seeding of redtop or of Chewing's fescue increased the weight of the tops and roots harvested.
8. Doubling the rate of seeding of Kentucky bluegrass in mixtures did not consistently increase production.
9. Where quick cover is not essential, sowing an adapted, desired turf grass alone would result in a more satisfactory turf than a mixture which includes the coarser, more aggressive nurse grasses.

LITERATURE CITED

1. BEAL, W. J. Lawn-grass mixtures as purchased in the market, compared with a few of the best. Proc. Soc. Prom. Agr. Sci., 1898:59–63. 1898.
2. BELL, R. S., and TEDROW, J. C. F. The control of wind erosion by the establishment of turf under airport conditions. R. I. Agr. Exp. Sta. Bul. 295. 1945.
3. DAVIES, J. G. Seed rates and interspecific competition in seed mixtures. Aust. Assoc. Adv. Sci. Rpt., 22:316. 1936.
4. DAVIES, W., and THOMAS, M. T. The behavior of grasses in the seeding year, when sown in pure plots: establishment, rate of growth, and palatability. Welsh Jour. Agr., 4:206–221. 1928.
5. FINDLAY, W. M. Report on grass seed mixtures. North of Scot. Col. Agr. Bul. 18. 1914.
6. LAPP, W. S. A study of factors affecting the growth of lawn grasses. Pa. Acad. Sci. Proc., 17:117–148. 1943.
7. MORGENWECK, G., Comparative seeding rate trials in pure sowings of grasses. Pflanzenbau, 17:24–30; 33–64; 75–92. 1940.
8. VAN DERSAL, W. R. The ecology of a lawn. Ecology, 17:515–527. 1936.

Light Reflection from Stubble Mulch[1]

T. M. McCALLA[2]

IN one system of land management for water and wind erosion control crop residues are left on the surface of the soil (2)[3]. These residues intercept the sun's rays, absorbing some and reflecting others. The amount of light absorbed by the soil has an important influence on soil temperature (4). In turn, soil temperature influences microbial activity and crop growth. It determines the rate of decomposition of crop residues and the production of available nutrients (3).

In the system of stubble mulching different types and amounts of residues are used. These residues are usually light colored immediately after harvest but later become considerably darker in color through decomposition by soil organisms. Some plant residues, such as straw, cover the soil completely, whereas other residues like cornstalks cover it only partially. Each cultivation of the soil breaks up the residues, hastening their decomposition and discoloration. From the time crop residues are returned to the land, they become darker in color. All of these conditions influence light reflection and consequently the temperature and environment of the soil for microorganisms and higher plants.

The purpose of this study was to compare the amount of light reflected by uncovered soil surface with that reflected by different types and amounts of residues during decomposition while left on the surface of the soil for protection against wind and water erosion.

EXPERIMENTAL

METHOD

Light reflection was measured with a Weston exposure meter and expressed as candles per square foot. When light reflection was being measured, the meter was held about 2 feet above the soil. A reading from a plot usually represented the mean of at least six individual determinations at different locations on the plot.

Readings were made in the field on plots with various treatments of plant residues. Different soil and weather conditions, including cloudy and clear weather, were represented. Most readings were made on clear or almost clear days. They were made over straw, cornstalks, sweetclover mulches, crops of different kinds, and from bare land for a comparison. They were made at different times of day and over different rates of mulch application.

SOILS

Marshall silty clay loam and Peorian loess were the two soils represented. The Marshall surface soil is dark colored and contains about 4% organic matter. The Peorian loess, taken from a depth of 10 to 20 feet neat Plattsmouth, Neb., is light brown in color and is practically devoid of organic matter.

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[1]Contribution by the Soil Conservation Service, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Neb., cooperating. Journal Series No. 408. Received for publication March 20, 1947.

[2]Bacteriologist, Soil Conservation Service, Research.

[3]Figures in parenthesis refer to "Literature Cited", page 696.

RESULTS

STRAW MULCHES

Amount, stage of decay, and background.—In the laboratory, dark and bright straw was applied at different rates to backgrounds of black felt, Marshall surface soil, and Peorian loess. Light reflection readings from these treatments exposed to artificial light are shown in Table 1.

The darker the background, the less was the light reflection. Dark straw, partially decayed, reflected less light than the bright straw. The rate of straw mulching influenced light reflection. In determining light reflection, the background, amount of mulch, and color of mulch are important.

Light reflection and temperature.—Plots with areas of 16 square feet were laid out on Marshall silty clay loam. One plot was mulched at the rate of 2 tons per acre with dark straw that had been exposed on the ground for 3 months, one with 2 tons per acre of bright wheat straw, and another was left bare.

Three thermometers were inserted to a depth of 1 inch in each plot at 9 o'clock a.m. (C.W.T.) on May 27, 1943. Beginning at 11 o'clock, soil temperatures were read each hour until dark. The data are shown in Fig. 1.

The bright straw reflected about twice as much as the partially decayed straw during most of the day. The bare soil reflected less

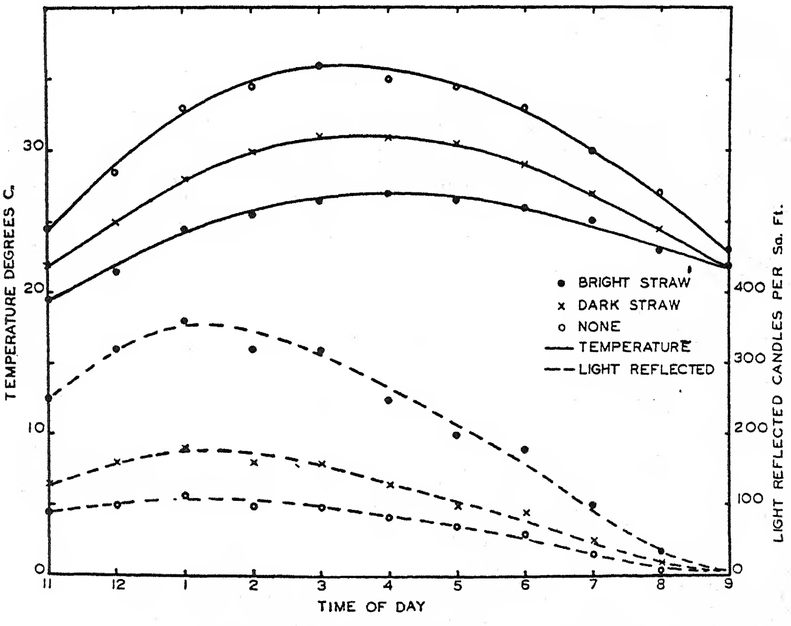

FIG. 1.—The influence of decomposition of straw mulch on light reflection and the temperature of the soil. Readings made at 1-inch depth on May 27, 1943. Straw mulch applied at the rate of 2 tons per acre.

light than either of the straw-mulched soils. The peak of light reflection came between 1 and 2 o'clock, while the highest soil temperature came between 3 and 4 o'clock. As might be expected, the plot reflecting the most light warmed the least during the day. For the bright straw mulch the light reflection curve declined at a more rapid rate after 1 o'clock than did the soil temperature curve. On the bare soil the temperature curve declined at a more rapid rate than the light reflection curve.

TABLE 1.—*Reflection of light as candles per square feet from different amounts of straw mulch as influenced by decay and background.*

Tons of straw per acre	Background and straw treatment*					
	Black felt		Marshall surface soil		Peorian loess	
	Dark straw	Bright straw	Dark straw	Bright straw	Dark straw	Bright straw
1/10	4	8	8	10	15	21
1/4	5	12	9	18	13	25
1/2	7	18	10	24	11	29
1	9	25	10	30	11	31
2	10	32	11	31	11	31
4	11	32	11	32	11	32

*Where no straw was applied, black felt gave 2 candles per square foot, Marshall surface soil 6 candles, and Peorian loess 16 candles.

Under field conditions the straw mulch seldom remains bright for more than a few weeks. Thus the influence of the straw mulch on soil temperature becomes less as decay proceeds.

Fallow.—Wheat straw at rates of 2, 4, and 8 tons per acre was applied to fallow plots 1 square yard in size, May 16, 1946. Bare plots were used for comparison. Plots were kept free of weeds with a hoe. The mean of the light reflection readings made at three different times during the month from 10 to 3 o'clock are given in Table 2.

The amount of light reflected by the straw mulch was almost double that reflected from the bare plots. At first, there was little difference in the amount of light reflected by the mulch applied at

TABLE 2.—*Light reflected in candlepower per square foot from straw mulch applied to plots fallowed through the summer, with straw applied May 16, 1946.*

Mean readings by months	Light reflection from unmulched plot	Increase in light reflection due to different applications of straw mulch in tons per acre		
		2 tons	4 tons	8 tons
May..........	82	52	65	65
June..........	82	52	65	68
July..........	73	23	33	36
August..........	87	23	37	37

the rates of 2, 4, and 8 tons per acre. This was due to the fact that there was almost complete ground coverage by all the mulch treatments at the beginning of the experiment. Later the straw mulch applied at the rate of 2 tons per acre did not reflect as much light as the 4- and 8-ton treatments. In general, as the season progressed, the light reflection from the mulched plots decreased. The large change in light reflection between June and July may have been due to rapid decomposition and discoloration of the straw mulch.

Rotation.—In a rotation of corn, oats, and wheat, plots 21 by 35 feet were triplicated. Crop residues grown on the land were returned each year. The light reflection readings were taken in the corn following wheat, with wheat straw as the mulch. Tillage for seedbed preparation and cultivation was accomplished by large, flat, V-shaped sweeps which left the residues on the surface. As a comparison, readings were made on plots with the residues plowed under. The residues from each crop in the rotation have been returned to the surface of the soil for a period of 8 years. The mean light reflection readings for three different times each month from a plowed and a subtilled plot are shown in Table 3.

The first readings were made in April, about 8 months after the residues were returned to the land. Prior to that time, part of which was winter, there had been some decomposition and discoloration of the mulch. However, even with decomposition and discoloration of the straw, the amount of light reflected from the mulched plots was still higher than from the plowed plots. After the corn was planted and had come up, the light reflection difference between the mulched and plowed land became less. By the middle of July there was no difference in the amount of light reflected by the plowed or subtilled plots. This was due to shading by the corn and to the disappearance and discoloration of the mulch. Shading by the corn in July reduced the light reflection from 73 candles per square foot on the bare fallow plot to 40 on the bare soil in corn (Tables 2 and 3).

TABLE 3.—*Light reflected from straw mulch in candles per square foot as compared to plowed land in a corn, oats, and wheat rotation, with readings made in corn following wheat.*

Mean readings by months	Light reflection from unmulched plot	Increase in light reflection due to mulching
April	93	67
May	68	45
June	82	32
July	40	0

SWEETCLOVER MULCHES

Light reflection from sweetclover mulch on land in corn was measured under two different field conditions. In one set of plots sweetclover about 12 to 14 inches high in the spring of the second year of growth was plowed under on one set of plots and left on the

surface on another set. In another group of plots the sweetclover was allowed to grow and mature in the second year. During the following spring some of these plots were plowed and others subtilled, leaving the residues on the surface. Light reflection from these conditions is shown in Table 4.

In both experiments more light was reflected from the mulched than from the plowed plots, but the difference between the plowed and mulched land was slight. After some decomposition had occurred, light reflection was the same from mulched or bare soil. Although there was a heavier mulch with the mature sweetclover, it rapidly became discolored and dark. The effect of light reflection on soil temperature under these conditions would be expected to be negligible. Consequently, the amount of light reflected from sweetclover land farmed by the system of stubble mulching would not be expected to influence soil temperature greatly.

CORNSTALK MULCHES

Some corn land plots were plowed, while others were subtilled leaving the cornstalks on the surface. The plots were replanted to corn in 1946. Light reflection from the cornstalk mulch and from bare land is shown in Table 4.

TABLE 4.—*Light reflected in candles per square foot from subtilled as compared with plowed corn land in 1946 following one and two years of sweetclover.*

Time of reading	First year sweetclover		Second year sweetclover		Corn after corn	
	Plowed	Subtilled	Plowed	Subtilled	Plowed	Subtilled
June 4, 3:30 p.m.	65	75	65	75	65	70
5, 10:00 a.m.	75	85	90	110	90	100
1:30 p.m.	65	75	65	90	70	90
12, 11:00 a.m.	65	75	50	65	50	60
25, 3:00 p.m.	80	80	80	100	80	80
27, 1:30 p.m.	100	100	120	130	120	120
July 17, 2:30 p.m.	40	40	40	40	40	40
22, 2:00 p.m.	40	40	40	40	40	40

Cornstalk mulch on land in corn reflected only slightly more light than plowed land in corn. This was probably due to the dark gray color of the residues and to only a partial covering of the land by cornstalks.

DISCUSSION

Mulching the soil with plant residues may influence crop growth and be reflected in the yield of grain and forage. Nitrate production influences crop yields directly and is itself influenced by soil temperature. One of the factors influencing soil temperature is soil color (1). Another is light reflection; that is, the light reflected is not absorbed and does not warm the soil.

As the crop residues left on the surface decompose, they become darker in color. This change results in less light reflection and more heat absorption. A dark paper mulch may actually increase the temperature of a bare soil. Soil mulched with paper may get as much as 19° F hotter than bare soil (5). By the time a crop is harvested, the mulch from the previous crop may be largely decayed. Some crop residues, such as cornstalks or corncobs, afford only a partial cover of the ground even at the time of application.

Crops growing on the land absorb or reflect a considerable part of the sun's rays. Frequently, the growing crop shades the soil more than the mulch. Light reflection would undoubtedly play a role in reducing evaporation from mulched soil. For moisture conservation this would be advantageous. However, since there is not much light reflection except at the beginning of the growing season, this factor would not be of major consequence, except in the early spring.

Under field conditions, with a growing crop, no appreciable amount of sunlight is reflected by a stubble mulch after decomposition and discoloration have occurred. This would not be expected to influence biological activity appreciably except perhaps in the early spring when nitrates may be retarded slightly.

SUMMARY

In the laboratory, dark and bright straw was applied at different rates to backgrounds of black felt, Marshall surface soil, and Peorian loess. Light reflection readings were made from these treatments exposed to artificial light.

Light reflection and soil temperature readings were made simultaneously from field plots mulched with dark and bright straw. In addition, light reflection was measured on mulched and bare soil in the field. The residues were cornstalks, sweetclover, and straw. Most of the mulched land was cropped to corn, but some was summer fallowed.

Dark straw reflected less light than bright straw. The rate of straw mulching also influenced light reflection.

There was a close relationship between light reflection and soil temperature. The soil mulched with bright straw reflected the most light and warmed the least. The bare soil reflected the least light and warmed the most. The soil with the dark straw mulch was intermediate in its effect on light reflection and soil temperature.

When bright straw was used that completely covered the Marshall surface soil, more than twice as much light was reflected from the mulched as from the plowed land. Since a 4-ton application of straw residues covers the soil completely, no additional reflection was obtained by increasing the rates of application up to 8 tons per acre.

As decomposition progressed, there was less ground coverage and the residues became darker in color with less light reflection. Under many conditions of stubble mulching in the field, light reflection was not much greater on mulched than on plowed land. Shading of the land with growing corn reduced light reflection about 50%.

LITERATURE CITED

1. BAVER, L. D. Soil Physics. New York: John Wiley and Sons, Inc. 1940. (Page 272.)
2. DULEY, F. L., and RUSSEL, J. C. New methods of rainfall and soil moisture conservation. Neb. Crop Growers Assoc. Ann. Rpt., 31:52–62. 1939.
3. MCCALLA, T. M., and RUSSEL, J. C. Nitrate production as affected by grain crop residues on the surface of the soil. Neb. Agr. Exp. Sta. Res. Bul. 131: 1–21. 1943.
4. ——— and DULEY, F. L. Effect of crop residues on soil temperature. Jour. Amer. Soc. Agron., 38:75–89. 1946.
5. STEWART, G. R., THOMAS, E. C., and HORNER, J. Some effects of mulching paper on Hawaiian soils. Soil Sci., 22:35–59. 1926.

The Moisture Content of Various Hays in Equilibrium with Atmospheres at Various Relative Humidities[1]

S. T. DEXTER[2]

IT is well recognized that some of our hays are difficult to cure. In some cases this is due to the weather conditions at the time of year at which they must ordinarily be cut, as in the case of soybean hay. Or the hay itself may have thick, succulent stems that dry out very slowly, as in the case of sweetclover.

For a good many years, the author has been working with hays cut at rather immature stages. Here another difficulty is sometimes encountered. These hays are so low in fibre that the stems lack stiffness and the hay packs down badly, either in the windrow, cock, or mow. In experiments 10 years ago, it was found impossible to cure such hays in ordinary cocks, or in any way where much pressure on the hay developed. Furthermore, immature hays that were almost dry in the evening often appeared to be much damper the next morning than would have been expected with mature hays. In one experiment very young oat hay was harvested. Late in the afternoon it was almost dry so was put in large cocks since the weather was threatening. No rain fell, although the relative humidity was high. The next morning moisture determinations on this hay showed that it was far too wet to be hauled. Part of it was spread out in the driveway of a barn, and frequently turned. Each night it appeared to become wet and finally it became musty and was thrown out. Other similar experiences with immature hay prompted the present experiments in which the moisture equilibria of hays at various relative humidities were measured.

A convenient way to obtain various relative humidities in a closed container is with the use of solutions of sulfuric acid of various concentrations. Directions for making such solutions may be obtained from the International Critical Tables. These solutions were placed in glass jars in which perforated cans were hung. The samples of hays were placed in the cans, where, in a period of a week or 10 days, they come to constant weight. If large samples of hay are used, it is necessary occasionally to correct the concentration of the solution by adding water. For ordinary purposes it is more convenient, and probably more accurate, to use samples small in proportion to the volume of the solution used. In such a case, several samples can be run at one time, and the solution can be used for some time before the water withdrawn or added is sufficient to become significant.

In the case of the samples described in this paper, the hays were air-dry when placed in the relative humidity chambers. The percentage of moisture was determined by loss of weight in an oven at 103°C. The content of moisture at equilibrium is shown in Table 1. Dexter, *et al.*

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(1)[3] have published data giving the moisture equilibria for alfalfa hay. Composite data from this paper are included for comparison.

In Table 1, the moisture equilibrium values for bromegrass hay of three maturities is given. The "very young" consisted of leaves before any of the heads had emerged, the "young" of plants with the heads just out of the boot, and the "overmature" of plants that had gone to seed. It is notable that, as the humidity rises, the more immature hays become distinguished by their high content of water in comparison with the mature hay. On all samples, values of moisture content at 90% relative humidity and above are very erratic. These samples are covered with mold, and in the samples higher in water may be little but masses of mold. The analyses, therefore, sometimes represent more nearly the percentage of water in mold than in samples of hay. It is notable that all of the samples of immature hay, high in protein, seem to contain considerable amounts of the substances that attract water at high relative humidities.

TABLE 1.—*The percentage of moisture in various hays at equilibrium with atmospheres at the relative humidities shown.*

Kind of hay	Percentage moisture at relative humidity of								Protein, %
	25%	50%	65%	70%	75%	80%	85%	90%	
Mature alfalfa (av. 4 samples)	6.26	9.30	11.5	12.8	14.3	16.5	19.4*	23.5*	—
Very immature alfalfa	12.4	10.8	13.0	—	16.6	22.4*	26.0*	24.2*	—
Red clover, immature (2nd cutting)	6.90	10.2	12.9	—	16.8	18.6	22.0*	26.0*	—
Immature ladino clover	9.4	12.4	13.9	17.2	18.6	24.5*	—	29.9*	30.3
Very immature bromegrass	—	8.97	12.6	16.4	—	20.6*	23.2*	26.7*	30.9
Immature bromegrass	—	8.43	11.9	15.3	16.2	20.5	22.9*	29.8*	13.0
Over-mature bromegrass	—	8.92	8.0	10.5	11.1	12.0	15.8*	23.4*	3.4
Immature timothy	—	8.2	11.3	12.9	15.4	20.6	19.9*	26.1*	14.0
Oat straw	5.5	7.4	9.7	—	12.0	13.9	19.3*	21.9*	—
Rye straw	—	8.1	10.4	12.0	12.5	12.7	16.8*	18.8*	1.0

*Moldy.

In a paper by Snow, *et al.* (3) curves for moisture equilibria are shown for starches, fibre, and protein, as well as for feeds of many sorts. Remarkable differences in moisture content at different relative humidities are shown in the different feeds. The shapes of the curves for purified materials are particularly instructive. Briefly, it may be said that the moisture content of the fibre was relatively low at all relative humidities; that of starch was high at low humidities, but as low as fibre at high humidities (a flat curve); while the moisture content of the protein was intermediate at low humidities, but very high at high humidities. Mixtures of the starch and protein in various proportions gave the values that would be expected from the sums of the fractional values of the components of the mixtures.

[3]Figures in parenthesis refer to "Literature Cited", p. 700.

The degree and rapidity with which molds form in hay samples appear to be more nearly a function of the relative humidity than of the moisture content of the material. Thus, it has been shown (2) that many mold spores will not germinate readily at relative humidities less than about 80%. At the end of 10 days of storage all samples from rye straw to immature ladino clover were moldy at 85% and at 90% relative humidity. At 80% relative humidity some mold had formed in the case of the very young brome grass and young ladino clover. Snow (2) states that, "The occurrence of mold was primarily a function of the relative humidity" in the six feeding substances that he used rather than a function of the moisture content. It was to some extent a function of the availability and balance of the food for the mold, but this was more a matter of degree of development than of occurrence, since one material may be a better medium than another and thus permit more rapid mold growth.

In the curing of immature hay, therefore, we are confronted with several distinct problems. First, the hay, because of its composition, tends to hold or to take up water readily from air at high relative humidities. Being less coarse than more mature hay, with thinner stems, more leaves, etc., it can take up moisture more rapidly, as well as to a greater content at equilibrium. Secondly, it makes a better medium for mold growth than does mature hay, particularly at borderline relative humidities. In addition, the hay, either in windrow, cock, or mow, packs down readily. This inhibits the flow of outside air, thereby maintaining a relative humidity too high to avoid molding. It should be plainly recognized that any hay at 25% moisture will mold readily if stored in a container sufficiently closed that the hay can maintain its full vapor pressure. Immature hay at 15 or 20% moisture actually has a lower vapor pressure than ordinary mature hay. In a closed container it will actually maintain a lower relative humidity than mature hay and may actually mold less than the mature hay. Thus, young ladino hay will maintain a moisture content of 17 or 19% at relative humidities of 70 or 75% with no sign of mold in several weeks of storage, whereas rye straw and mature bromegrass molded in 10 days when stored at a relative humidity of 85% and a moisture content of 15 or 16%. Under the conditions of varying relative humidity in the field, the tissues of the young stems appear to regain their turgidity far more readily than do those of mature stems. Thus, each morning, one appears almost to start the curing process anew, with the cells of the inner leaves, etc., fresh and turgid.

Another problem closely related to these is clarified by these figures. Cured Ladino clover in an atmosphere of 75% relative humidity had a moisture content of 18.6%, young bromegrass 16.2%, and mature bromegrass, rye straw and oat straw 11.1, 12.5, and 12.0%, respectively. A relatively small uptake of water by the immature hays would be sufficient to bring them to moisture contents dangerous for storage. Thus, shorter periods of humid weather would be sufficient to cause spoilage than in the case of the drier forages. Such difficulty with immature grass hays has been reported (4).

In order to compare certain hays in more detail, the following samples were taken from one lot of second cutting alfalfa: (a) Ordi-

nary alfalfa; (b) alfalfa from adjacent plants that had been shaded for a period with straw until they had lost a considerable part of their green color; (c) ordinary alfalfa dried and then leached for 2 hours in running water; (d) the top portions of the stems in comparison with (e) the bottom portion of the stems. The data are given in Table 2.

TABLE 2.—*The percentage of moisture in various alfalfa hays at equilibrium with atmospheres of the relative humidities shown.*

Type of hay	Percentage moisture at relative humidity of						
	25%	50%	65%	75%	80%	85%	90%
Ordinary	6.44	9.6	11.9	13.4	16.5	20.5*	25.2*
Shaded	6.05	9.9	11.6	14.1	18.0	19.0*	23.6*
Leached	4.69	7.5	10.1	12.8	15.3	16.8*	21.5*
Top of stem	8.36	9.97	12.1	15.0	17.3	21.0*	23.4*
Bottom of stem	6.27	8.88	11.6	14.0	15.1	18.2*	22.1*

*Moldy.

There appears to be but little difference in the moisture equilibria of shaded vs. unshaded alfalfa, whereas leached alfalfa seemed definitely less hygroscopic than unleached hay. At every relative humidity the top of stems appears to be higher in moisture than the bottom. We would anticipate that the content of both starch and protein would be higher in the top portion of the stem than in the bottom portion, whereas the fibre would be higher in the bottom portion than in the top, and, from the work of Snow (3), we would expect more moisture at equilibrium in the top than in the bottom of the stem.

SUMMARY

Values for the moisture content of various mature and immature hays at various relative humidities are given. It is shown that immature hays are higher in moisture content at high relative humidities than are mature hays. Molding was visible on all samples of hay and straw within 10 days at a relative humidity of 85%. The amount of mold development at 85% relative humidity was greater in immature hays than in mature hays or straws. The development and occurrence of molds was determined by the relative humidity of the atmosphere rather than by the moisture content of the hay. Thus, an immature hay at 17 or 18% moisture might show no sign of mold (at 75% relative humidity) when a mature hay at 15 or 16% moisture and a relative humidity of 85% was plainly molded. To avoid relatively prompt molding in any hay, the relative humidity of the surrounding atmosphere must be kept below 85%.

LITERATURE CITED

1. DEXTER, S. T., SHELDON, W. H., and WALDRON, DOROTHY I. The equilibrium moisture content of alfalfa hay when exposed to air at various relative humidities. Agr. Eng., 28:295–296. 1947.

2. SNOW, D., *et al.* Mould deterioration of feeding stuffs in relation to humidity of storage. Part I. The growth of moulds at low humidities. Ann. Appl. Biol., 31:103–110. 1944.

3. ———. Mould deterioration of feeding stuffs in relation to humidity of storage. Part II. The water uptake of feeding stuffs at different humidities. Ann. Appl. Biol., 31:111–116. 1944.

4. WRIGHT, N. C. The storage of artifically dried grass. Jour. Agr. Sci., 31:194. 1940.

Factors Affecting Seed Rotting Caused by *Pythium* spp. in Sweetclover with Preliminary Tests in Alfalfa and Red Clover[1]

J. A. JACKOBS[2]

IN the regions of the United States where large acreages of small-seeded legumes are established each year, the number of seeds planted is four to eight times the number of plants required for a satisfactory stand. Inadequate coverage or too great a depth in placement of seeds and losses of plants from drought and competition, damage by insects, frosts, and excessive rains are generally given as the reasons for the failure of seedlings to become established. The invasion of seeds and seedlings by pathogenic organisms has also been a contributing factor.

Damping-off has been reported to reduce stands of small-seeded legumes. Stewart, French, and Wilson (8)[3] in 1908 reported that *Pythium debaryanum* Hesse caused damping-off of greenhouse-grown alfalfa seedlings. Buchholtz (2) found that failures of alfalfa stands were due sometimes to damping-off caused by *P. debaryanum*. He reported a total emergence of 38.1, 52.5, and 59.2% for alfalfa, sweetclover, and red clover, respectively, in the field. Chilton and Garber (3) reported that only 12.9 and 15.8% of the seeds of *Melilotus alba* Desr. and *M. officinalis* (L) Lam. established seedling plants when planted in greenhouse soil. Data presented by Allison and Torrie (1) show that the total emergence in their field trials was 94.2, 83.3 and 65.0% for alfalfa, white sweetclover, and red clover, respectively. In the latter cases the causal agents that prevented emergence were not determined.

Differences have been observed in the reaction of various species and varieties of plants to certain species of *Pythium*. Buchholtz (2), in preliminary experiments, observed that such "acid tolerant" legumes as red clover, alsike clover, and white Dutch clover might be somewhat resistant to damping-off. Welch (9) presented data that showed a varietal difference in the reduction in germination of oats due to *P. debaryanum*. It was found that from 30 seeds, 28 seedlings of the variety C. I.3601 and 24 seedlings of Nakota emerged from noninfested soil, while in soil infested with *P. debaryanum*, emergence in the two varieties was 27 seedlings and 1 seedling, respectively.

Preliminary field studies at Madison, Wis., indicated that differences similar to those reported in oats by Welch (9) exist in sweetclover. In 1944 the range in emergence under field conditions varied from 45 to 91% in seed lots of *Melilotus alba*. The investigations

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[3]Figures in parenthesis refer to "Literature Cited", p. 717.

reported here were undertaken to determine why viable seeds rotted in the soil and whether differences in stand may be due to genetic differences that can be utilized in a plant breeding program.

MATERIALS AND METHODS

Commercial seeds of standard varieties, greenhouse- and field-produced seeds of experimental lines and varieties, and seeds from roadside sweetclover plants were used in the experiments. Seeds of experimental varieties of sweetclover were obtained from Dr. W. K. Smith, of alfalfa from Dr. R. A. Brink, and of red clover from Dr. J. H. Torrie and Dr. J. L. Allison.

Sound seeds that would germinate well were selected for the tests. In most instances open-pollinated seeds were used. Mature and immature seeds were collected from some plants.

The seeds were scarified by placing them in concentrated sulfuric acid or by nicking them with a razor blade. When they were placed in concentrated sulfuric acid, sweetclover seeds were left 17 minutes and alfalfa and red clover seeds 8 minutes, then rinsed rapidly in water and dried. Acid treatment does not scarify all the seeds so it was used only in experiments where the seeds that remained hard could be recovered and scarified with a razor blade. In the latter method they were nicked over the cotyledons on the side away from the hypocotyl since breaks in the seed coat in the region of the hypocotyl are conducive to seed-rotting.

The proportion of viable seeds in each sample used was determined by germination tests. The seeds were placed either on moist blotters or moist sand in Petri dishes.

In the greenhouse and field experiments the seeds were planted, with the aid of a planting board, in rows 2½ inches apart and 1½ inches apart in the row at a depth of ½ inch. In the fall of 1945, the planting board was not used in the field variety trial; instead, the seeds were planted in a furrow ½ inch deep.

The proportion of the viable seeds that produced seedlings was determined for each lot of seed planted. Two weeks or later after the seeds were planted all seedlings that emerged were counted. Notes were taken on post-emergence damping-off when it occurred.

Two soils were used in the greenhouse tests. One was a mixture of equal parts of a dark-brown soil taken from the top 12-inch layer under an oak-hickory stand and of a compost soil obtained from a stock-pile several years of age prepared by stacking bluegrass and clover sod. The other soil was the top 6-inch layer taken from a field where several crops of alfalfa and sweetclover had been grown. These soils will be referred to as woods-compost and field soil, respectively. In both soils damping-off was known to have occurred.

Fungus isolations were made on water-agar plates from seeds that had been in soil 24 to 72 hours. It was possible to free the original isolates from bacterial contaminations by one or two marginal sub-transfers on water-agar plates.

Pathogenicity tests of the fungal isolates were made by germinating seeds of a seed lot that did not emerge well in the field on sand in a Petri dish in which the isolate was growing. Transfers of the isolate to be tested were made to a sterile Petri dish containing approximately 10 cc of potato-dextrose agar. After the mycelia covered the plate, 100 grams of dry sterile sand was poured into the Petri dish and 10 cc of tap water added evenly over the surface. In most cases the mycelium grew rapidly through the sand and formed a light fluffy mat on the surface. Five or six shallow furrows were drawn on the surface of the sand and seeds were placed in them. The sprouted seeds were removed in the next 72 hours at 24-hour intervals. The proportion of viable seeds that rotted before the hypocotyl elongated was used as an indication of the pathogenicity of an isolate. Re-isolations were made from the rotted seeds and the isolates were tested again.

Isolate-variety comparisons were made using the same technique employed in the pathogenicity tests. Seeds of several varieties were placed on a plate at the same time.

All the experiments were designed so that it was possible to determine the statistical significance of differences between one or more sets of factors.

EXPERIMENTAL RESULTS

DESCRIPTION OF ROTTED SEED

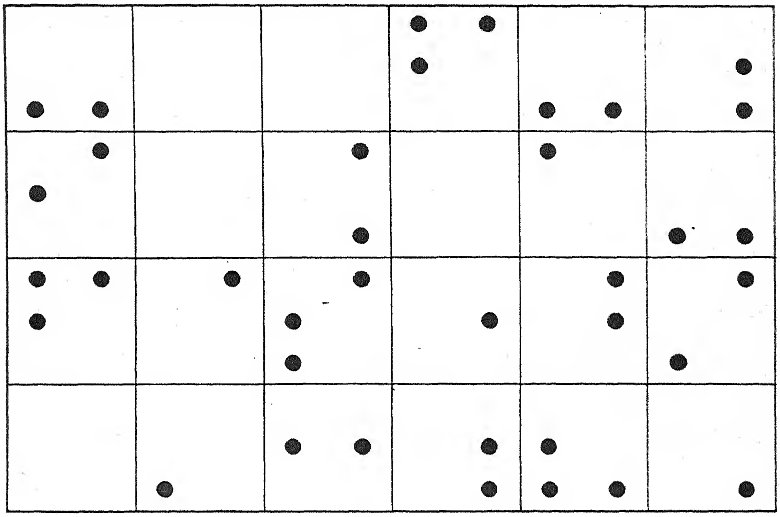
Seeds that had been planted in soil were studied to determine what happens to those that fail to emerge. Seeds were planted in seven Petri dishes containing woods-compost soil. Every 24 hours the seeds in one of the Petri dishes were washed out. The seeds that had remained in the soil 72 hours or longer could be placed into two classes. One group of seeds had germinated and the hypocotyls had elongated at least ½ cm. The other group of seeds had hardly begun to germinate before they rotted. The root tip had just broken through the seed coat of some in this group. There were no gradations between these two groups. If the hypocotyl of a seedling began to elongate, it continued to grow until it was at least ½ cm long regardless of whether or not it was invaded by the fungus. Isolates from both classes were capable of causing seed-rotting. The lack of intermediate classes between the two groups that are invaded by the fungus indicates that the seed-rotting phase is distinct from other phases of damping-off though the causal organism may be the same.

CAUSAL ORGANISMS

Isolations were made from sweetclover seeds that were planted in the woods-compost soil and in the field soil and left for 24 to 72 hours. The isolations were made from whole seeds and from embryos with the seed coat removed. The isolates were predominantly pythiaceous although isolates of *Rhizoctonia*, *Fusarium*, and *Mucor* were frequently recovered. Certain isolates of the genus *Pythium* proved to be pathogenic. Known cultures of *P. debaryanum* and *P. ultimum* Trow were found to be pathogenic. The pathogenic isolates resembled these species but positive identifications were not made. Therefore, the rotting of viable sweetclover seeds can result from the presence in the soil of *P. debaryanum* and *P. ultimum* and possibly other species of the genus *Pythium*.

RANDOM OCCURRENCE OF SEED-ROTTING

Post-emergence damping-off is frequently observed to spread from centers of infection and most of the seedlings in localized areas are invaded by the fungus. In this case the location of a seedling in the seedbed largely determines whether it will become diseased. The distribution of seeds that failed to emerge was studied to determine if the seed-rotting occurred in a similar pattern. Six flats of woods-compost soil were planted each with 144 seeds of Cossack alfalfa in 12 rows and 12 columns. The location of each seedling that failed to emerge was indicated on a diagram of the flat. The distribution of the seeds that failed to emerge in flat 4 is shown in Fig. 1. The X^2 test described by Cochran (4) was used to determine whether they were distributed at random in each flat. A similar test was conducted in the field where three plots each of Cossack alfalfa, Grimm alfalfa, and A 46 (a strain of *Melilotus officinalis* used as a check in these experiments) were planted. In only one case in 15, P was less than .05. The chances of a seed emerging were the same regardless of whether



$\chi^2 = 18.61$ P = .95 - .50

FIG. 1.—The distribution of Cossack alfalfa seeds that failed to produce seedlings in a flat of woods-compost soil.

$$X^2 = \frac{n\Sigma Nr(r-\bar{r})^{2*}}{r(n-\bar{r})}$$

* r = Number of seeds that failed to produce seedlings in a particular group; Nr = Number of groups of *r*; n = Number of seeds planted in each group or 6.

its neighbors emerged or not. This indicates that the centers of infection either were extremely small and occurred at random or, more likely, the chances of a seed emerging were the same regardless of where it was planted. If a seed rotted, it did not increase the likelihood of its neighbors rotting.

FIELD AND GREENHOUSE VARIETY TRIALS

The percentage of viable seeds that produced seedlings was determined for several varieties in randomized-block field and greenhouse experiments. The results are given in Tables 1 and 2.

In both the field and the greenhouse the percentage of viable seeds that emerged from the soil differed from one seed lot to another in alfalfa and each of the two species of sweetclover tested. However, the differences found among red clover seed lots were not significant. All the red clover seed lots, except the commercial sample, were grown in the same year under similar conditions.

The emergence of viable seeds of comparable genetic composition varied widely in the 1945 field trial (Table 1). The seed lots C. Y. 43 and C. Y. 45 were collected from roadside plants of *M. officinalis* at the same location in 1943 and 1945, respectively. The seed lot L 237 was collected from nursery plants in 1945 that were grown from seed of C. Y. 43. Presumably, the genetic composition of these three lots of seed was similar since the genetic composition of a population would

not shift much in one generation without selection. There were wide differences in the percentage emergence of viable seed between these seed lots (Table 1, column 3). Similarly, the seed lots, C. W. 43 and C. W. 45 were collected in the same location in 1943 and 1945 and the difference in the emergence of viable seeds was large. Since the emergence of seed lots of comparable genetic composition produced under different conditions was not similar, nongenetic factors which affected the seed-producing plant must have influenced the percentage of viable seeds that emerged.

TABLE 1.—*The percentages of viable seeds, seeds that produced seedlings, and viable seeds that produced seedlings from seed lots of sweetclover, alfalfa, and red clover planted in the field at Madison, Wis., September 26, 1945.**

Variety	Percentage viable seeds	Percentage emerged†	Percentage viable seeds emerged
Melilotus Officinalis			
C.Y. 43	82	65	80
C.Y. 45	93	60	65
L 237	97	42	43
A 46	78	26	34
Melilotus alba			
C.W. 43	80	39	49
C.W. 45	89	57	65
White sweetclover	45	18	40
Evergreen	84	48	57
Wisconsin late	95	51	54
Sangemon	84	32	38
Iowa late	74	15	20
Medicago sativa			
Cossack alfalfa	93	58	63
Ranger alfalfa	92	49	53
Trifolium pratense			
Red clover	95	27	28

*Results are based on 400 seeds of each variety planted in four replicates, 100 seeds in a replicate.
†Least significant difference (5%) = 11; (1%) = 14.

In the greenhouse, no relationship was found between the percentage emergence of viable seeds and seedling difficulties after emergence. After the seedlings emerged, counts were made of healthy seedlings, nonvigorous seedlings, and dead seedlings (Table 2). The varieties are listed in the order of the percentage of viable seeds that emerged, and it is apparent that there was no tendency for the percentage of healthy seedlings to be low where the percentage of seeds that produced seedlings was low.

SOIL TEMPERATURE AND SEED ROTTING

Buchholtz (2) has shown that post-emergence damping-off in alfalfa is influenced by temperature. The following experiment was conducted to determine if pre-emergence damping-off is also in-

fluenced by soil temperature. Two flats of soil were placed in a sash house and each of three temperature-controlled greenhouses. One flat at each location contained woods-compost soil and the other contained field soil. Twelve seeds each of 12 varieties were planted in each flat. Eighty-nine per cent of the seeds emerged from the field soil and 80% emerged from the woods-compost soil. There were significant differences among varieties similar to those found earlier. Eighty-eight per cent of the seed emerged where the soil temperature was maintained at 7° to 8°C; 83% at 14° to 15°C; 83% at 16° to 19°C; and 84% at 19° to 22°C. These differences are not significant, indicating

TABLE 2.—*The percentages of viable seeds, seeds that produced seedlings, and healthy seedlings (based on number of seeds emerging) from seed lots of sweetclover, alfalfa, and red clover planted in woods-compost soil in the greenhouse.**

Variety or strain	Percentages of			
	Viable seeds	Seeds emerging†	Viable seeds emerging	Healthy seedlings
		Sweetclover		
K 395-17	100	97	97	97
K 141-1	100	95	95	100
C. Y. 43	100	93	93	82
C. W. 43	100	87	87	94
D 236-2	100	73	73	91
A 46	100	53	53	100
		Alfalfa		
Co 196	28	30	100	85
Co 296	66	65	98	82
A 125 B	88	93	94	86
C 113	93	75	81	93
C 70	79	63	80	92
C 68	76	60	79	88
A 31 B	86	62	72	91
Ac 292	89	62	70	83
C 102	94	62	66	89
116	95	62	65	92
Ranger	83	53	64	93
C 119	88	47	53	86
C 117	89	30	34	89
		Red Clover		
F. C. 13,274	64	78	100	93
31×35	92	98	100	100
42×38	97	98	100	95
43×48	93	98	100	85
23×64	99	98	99	85
27×33	98	97	99	91
37×15	96	95	99	100
26×27	96	95	99	93
40×39	98	90	92	94
Commercial	98	88	90	81

*Results are based on 60 seeds of each variety planted in five replicates, 12 seeds in each replicate.

†Least significant difference (5%) = 15; (1%) = 20.

that in this experiment differences in soil temperature between 7° and 22° did not influence the number of seedlings that emerged.

SEED ROTTING ON SAND CONTAINING MYCELIUM OF PYTHIUM

Obviously it is not possible to observe seeds planted in soil throughout the germination period to determine the effect of *Pythium* since the seeds are covered and other organisms in the soil obscure the picture. Likewise, if a seedling does not emerge, it is very difficult to recover the seed. It was more convenient to use Petri dishes with moist sand containing mycelium of *Pythium* to germinate seeds for this study as the seed remained on the surface and other fungi were excluded. Seeds germinating on this medium, with and without pathogenic isolates, were examined with an 8× binocular so that it was possible to observe what happened to the seed in some detail. Thirty-six field-collected seeds of *Melilotus officinalis* were examined in the presence of the fungus and a similar group without the fungus. Thirteen seeds rotted in the presence of the fungus and seven rotted where the fungus was not introduced. Where the fungus was present a gelatinous material was associated with 69% of the rotted seed and in no case was it associated with the seeds that germinated. In the absence of the fungus the gelatinous material was associated with 19% of seeds that rotted and it was also associated with 7% of the seeds that did germinate. The gelatinous material collected between the hypocotyl and cotyledons within the endosperm, as described by Martin and Watt (7), and caused the seed to be distended. It frequently gathered over the hilum scar and defects in the seedcoat. The consistency of the material was greater when the seed germinated in the presence of the fungus and mycelium became concentrated around such seeds. This material may be a by-product of the metabolism of the germinating seed and is formed when the normal processes are disturbed. The pathogenic isolates used in this study may be capable of causing such a disturbance.

There was an association between the type of seed coat fracture and seed-rotting during germination. In the previously mentioned group of seeds, it was found that 43% of the seed coats of seeds that germinated in the presence of the fungus were ruptured close to the hilum by the emerging root tip. None of the seeds that rotted in the presence of the fungus had this type of rupture although 83% had ruptures elsewhere.

ISOLATE-VARIETY STUDIES

Seeds of five varieties that had been tested extensively in soil were germinated, using the same technique employed in the pathogenicity tests in order to determine the relationship between emergence in the field and seed-rotting where only *Pythium* was present. In this way it was hoped to obtain some information on the importance of the isolates in causing seed-rotting in the field. All the seeds were scarified with a razor blade before they were placed on moist sand. Ten seeds of each variety were placed on each of 20 plates. Five plates contained the mycelium of isolate G 8 (3); five, isolate R. C. (2); five,

isolate 77; and five, no fungus mycelium. When the seeds had germinated and the seeds or seedlings had been removed, the plates were used again in another test. The experiment was repeated using 20 fresh plates. Fig. 2 shows the number of seeds that germinated after 24, 48, and 72 hours. Table 3 summarizes the experimental results and Table 4 compares the amount of seed rotting in this experiment with the amount of pre-emergence damping-off that occurred in plantings in soil.

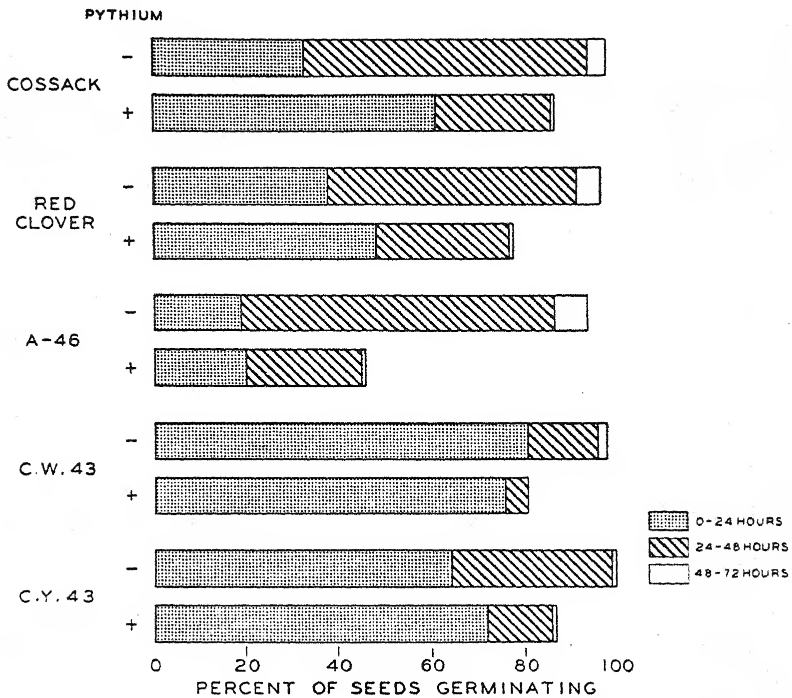


FIG. 2.—The percentage of seeds of three varieties of sweetclover, of Cossack alfalfa, and of red clover that germinated in the presence and in the absence of the fungus.

The F values in Table 3 indicate that there were highly significant differences among varieties, but the differences between isolates were not significant. There was a highly significant difference in the number of seeds that germinated in the check and in the presence of the fungus. There were no interactions between seed lots and isolates, that is, all isolates caused the same amount of seed-rotting in any one seed lot.

The number of seeds that failed to emerge from the soil was comparable to the number of seeds that rotted when germinated on moist sand containing mycelium of pathogenic isolates (Table 4). In the three seed lots of *Melilotus*, the percentage of seeds that rotted on sand in the presence of the fungus is in agreement with the percentage

of seed of the same lots that failed to emerge from soil. Emergence in the field is undoubtedly influenced by other factors, such as crust formation on the soil surface and fungi other than the species of *Pythium* studied, and these may account for the low percentage of emergence for red clover in the field in 1945.

TABLE 3.—*Germination of alfalfa, red clover, and sweetclover on sand in presence of three pathogenic isolates of Pythium and the analysis of variance.*

Variety	Number of seeds germinating out of 200 with isolates			
	G 8 (3)	R. C. 2	77	Check
Cossack	168	176	178	196
Red clover	154	161	147	194
A 46	82	92	98	188
C. W. 43	161	165	172	195
C. Y. 43	165	176	179	199
Totals	730	770	774	972

	Degrees of freedom	Mean square	F value
Varieties	4	148.0	72.2**
Isolates	3 {1 ck vs. I	344.0	167.8**
	{2 betw. I	6.0	2.9
Runs	1	37.0	18.0**
Times	1	15.0	73.2**
V×I	12 {4 V×(ck vs. I)	35.0	17.1**
	{8 V×I	2.1	1.0
T×R	1	3.0	1.5
Error No. 1 and 2†	57	2.05	—
Plates	64	2.00	—
Error No. 3	256	1.13	—
Total	399		

**Highly significant.
†Error No. 1 and error No. 2 were equal so they are combined.

TABLE 4.—*The percentage of seeds that germinated on sand in the presence of Pythium and the emergence of seedlings from soil.*

Variety	Field in fall 1945	Greenhouse		Petri dish sand and *Pythium*
		Bench	Soil temperature experiment	
Cossack	62.8	73.3	81.2	88.8
Red clover	27.8	89.8	85.4	79.4
A 46	33.7	51.7	63.5	48.2
Common white	49.1	86.7	79.2	84.7
Common yellow	79.5	95.0	89.7	86.7

In addition to causing seed rotting the presence of the fungus had an interesting effect on germination. The fungus stimulated the rate of germination during the first 24 hours in three of the five varieties

tested (Fig. 2). The number of Cossack alfalfa seeds that germinated in the presence of the fungus in the first 24 hours was 18% greater than the number that germinated in the checks. Somewhat less stimulation was found in red clover and C. Y. 43. In A 46 and C. W. 43 enough killing may have occurred in the first 24 hours that it was not possible to detect any stimulation of the germination rate.

STAGE OF SEED DEVELOPMENT AND SEED ROTTING

To determine whether the degree of development of seed when harvested has an influence on the amount of seed rotting, seeds were collected from four greenhouse-grown plants at six stages of maturity, namely, 1, fully ripe, peduncle brown; 2, pods brown, peduncle green; 3, pods light brown; 4, pods green, full-size; 5, pods two-thirds size; 6, pods one-half size. The seeds were dried and stored at room temperature four months. Ten seeds or less of each class from each plant were germinated on sand in each of eight Petri dishes. Four plates contained mycelium of *Pythium* and four did not. The results are given in Table 5.

A large proportion of the seeds in classes 5 and 6 rotted in the presence of the fungus. Much less seed rotting occurred in the more mature seed classes. Seed class 5 is of particular interest. The checks show that a high percentage of the seeds was viable. Nevertheless, only from 15 to 33% of the seed germinated in the presence of the fungus. Viable immature seeds, therefore, are much more likely to rot in the presence of the fungus than comparable mature seed. However, it should be noted that in the seed from two plants there was a considerable amount of seed rotting in the more mature seed classes (Table 5).

TABLE 5.—*Percentage of seeds of sweetclover that germinated in the presence and absence of Pythium from seed collections made at six different stages of development.**

Plant	Fungus	Seed class†					
		1	2	3	4	5	6
L 318 (4)	+	100(36)	85	95	100(8)	25	0
	−	100	100	100	100(8)	98	50
L 318 (5)	+	95	96(24)	90	100(36)	33	2
	−	100	100(24)	100	100(36)	95	25
L 318 (8)	+	82	78	82	78(32)	19(16)	0
	−	100	100	100	100(32)	95(20)	28
L 245 (7)	+	82	78(32)	72	65	15	8
	−	100	100(32)	100	100	80	20

*Results are based on 40 seeds of each plant in each seed class except where the number of seeds is indicated in parenthesis.

†The seed classes are described in the text.

Seed rotting of mature and immature field-harvested seed was also studied. Seeds with dry, brown pods and seeds with green pods two thirds to full size were harvested from a large number of sweetclover plants. The seeds were dried and stored at room temperature

for a month. Thirty-three seeds of each class from a plant were put on sand in each of three Petri dishes. The results of tests on 19 plants are given in Fig. 3.

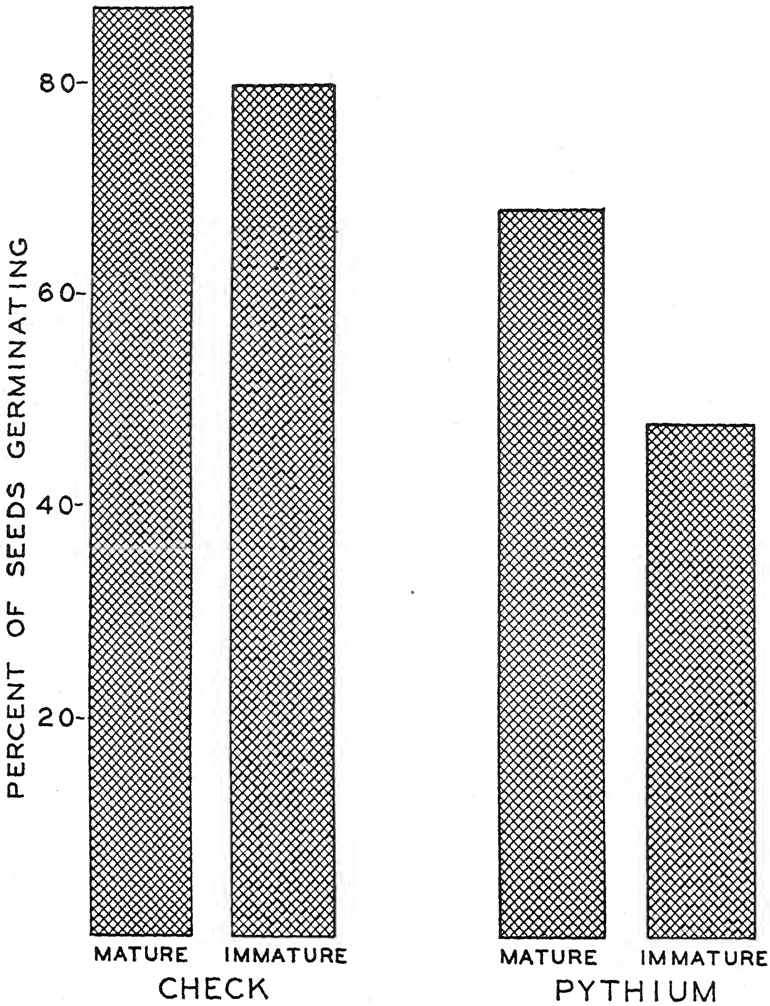


FIG. 3.—The percentage of mature and immature seeds of *Melilotus alba* that germinated in the presence and in the absence of *Pythium*.

The bar graph in Fig. 3 shows that the difference between the proportion of mature and immature seed that germinated was much greater in the presence of the fungus than in the check. In the analysis of variance (not shown), the F value for the interaction of maturity and check versus isolates is highly significant, indicating that in the presence of the fungus the difference in germination between the two

maturity groups is greater than the difference in the germination between the two maturities in the check. Further, the reduction in germination of viable immature seeds due to the fungus was greater than with comparable mature seeds.

The seed rotting of mature and immature seed was studied in greater detail with seed from four sweetclover plants grown in the nursery. Samples of mature and immature seed were collected from each plant. Eight seeds of the two classes from each plant were placed on moist sand in a Petri dish. Twenty-one plates were used. Seven plates contained isolate 4; seven, isolate 17; and seven, no fungus. The results are presented in Table 6.

Here, also, it is apparent that there is a real difference in the amount of seed rotting occurring in mature and immature seed. There are also highly significant differences in the amount of seed rotting in the seed from different plants. The spread in the amount of seed rotting between mature and immature seed differs between plants, but this might have been due to differences in degree of development and does not necessarily mean there were inherent differences between plants.

TABLE 6.—*The number of mature and immature seeds of M. alba out of 56 that germinated in the presence of two isolates of Pythium sp. and a check.*

Plant	Maturity of seed	Number of seeds germinating with isolates					
		4	Diff.	17	Diff.	Check	Diff.
C. W. 2	Ripe	36	5	41	10	54	2
	Green	31		31		52	
C. W. 3	Ripe	29	6	35	8	52	4
	Green	23		27		48	
C. W. 5	Ripe	47	16	51	18	55	3
	Green	31		33		52	
C. W. 10	Ripe	40	12	45	15	54	12
	Green	28		30		42	

Least significant difference (5% and 1%) for: Seed lots = 10;13. Plants = 7;9. Pl. × Mat. = 10; 13.

GENETIC DIFFERENCES BETWEEN SEED-PRODUCING PLANTS

To test further if genetic differences exist between plants that account for differences in the amount of seed rotting in the seeds they produce, ripe seeds were collected from 15 plants of *Melilotus officinalis* grown in adjacent rows in a nursery in 1945. Ripe seeds were also collected from eight roadside *M. officinalis* plants that grew in an area 300 by 100 feet. Within each group the environment of all the plants was very similar. Sixty seeds of each seed lot and two check varieties were germinated on sand in Petri dishes containing mycelium of a pathogenic isolate. A 5×5 balanced lattice experimental design was used. The experimental results are given in Table 7.

Within both the nursery group (L 237) and the roadside group (C. Y. 45) there are highly significant differences in seed-rotting in different seed lots. Since the plants within each group were grown under similar environmental conditions, the differences in seed rotting

in the various seed lots must be due to genetic differences between the seed-producing plants.

The amount of seed rotting was not correlated with the amount of stem-blackening of the seed-producing plant. Notes were taken on stem-blackening on a scale of 0 to 10 (0=no stem blackening; 10= severe stem blackening). The organisms causing this blackening were not identified, but in this nursery it is generally due to invasion by *Ascochyta lethalis* Ell. and Barth. and *Cercospora Davisii* Ell. & Ev. It is apparent that there is no correlation between stem blackening of a seed-producing plant and seed rotting in seed produced by that plant (Table 7).

TABLE 7.—*The percentage of seeds of 25 seed lots of Melilotus officinalis that germinated in the presence of Pythium spp.**

Plant	Percentage of viable seed	Percentage germination with fungus†	Stem blackening‡
L 237 (4)	97	87	7
(21)	100	87	2
(23)	98	83	8
(28)	97	83	9
(27)	100	82	4
(25)	100	77	10
(20)	98	75	4
(22)	99	73	4
(26)	98	73	1
(29)	99	70	5
(30)	97	62	8
(5)	100	50	5
(6)	83	50	9
(7)	98	48	8
(18)	96	35	7
C. Y. 45 (6)	98	90	—
(3)	100	87	—
(1)	99	82	—
(8)	100	80	—
(2)	99	75	—
(5)	95	63	—
(4)	96	53	—
(7)	96	43	—
C. Y. 43	98	77	—
A 46	68	25	—

*Results are based on 60 seeds of each seed lot planted in six replicates, 10 seeds to a replicate.
†Least significant difference (5%) = 18; (1%) = 25.
‡Numbers indicate severity of the disease. 0 = No stem blackening and 10 = very severe stem blackening.

DISCUSSION

The seed rotting caused by *Pythium* spp. reported here differs from the so-called "damping-off" caused by invasion of seedlings after the early stages of germination by the same organism. The occurrence of each is dependent on the presence of *Pythium* in the soil, but there is a clear distinction between rotting of seeds and invasion of the hypocotyl just prior to seedling emergence or near the soil line after emergence. The likelihood of a seed rotting is determined primarily by a condition of the seed itself, whereas the later invasion of the seedling

is influenced markedly by its environment. Grandfield, *et al.* (6) demonstrated that the pH of the soil influences both pre- and post-emergence damping-off in alfalfa, but the pre-emergence damping-off included in addition to seed rotting the blighting of seedlings before they emerged. Buchholtz (2) has also shown that pH and temperature of the soil influence the amount of post-emergence damping-off in alfalfa. The seed rotting reported in this paper is not influenced by soil temperatures in a range from 7° to 22°C and there is no association between the percentage of seeds that failed to emerge and the amount of post-emergence damping-off. Moreover, the random distribution of seeds that rot in soil suggests that small differences in local environment do not influence the chances of a seed rotting. It seems rather that something about the seed itself is more important, e.g., the degree of development of a seed when it is harvested and possibly abnormal fractures in the seed coat. In studies of fungal attack of legume seedlings, therefore, seed rotting should be clearly distinguished from invasion of the hypocotyl after germination is well advanced.

The extent to which a seed has developed is perhaps the most important factor in determining the ability to germinate when *Pythium* is present. A large proportion of the seeds that do not attain full size before they ripen may be viable, but they are less likely to sprout when germinated in the presence of the fungus than comparable seeds that are allowed to develop fully before ripening. The methods used in harvesting and processing commercial sweetclover seed undoubtedly contribute indirectly to the occurrence of seed-rotting in the field. The indeterminate type of growth of this plant makes it necessary to harvest the seed while a large proportion are still immature in order that a large share of the early ripening seeds are not lost due to shattering. The immature seeds that are heavy enough to pass through the seed cleaning operations are predisposed to rot when planted in soil. Erickson (5) reported that "the ratio between total live seed and soil germination progressively widened as the size of seed decreased (in alfalfa)."

During the germination of seeds in the presence of *Pythium* certain events are associated with the ability or inability of a seed to sprout. In no case was a seed observed to rot in the presence of the fungus when the seed coat fractured near the hilum scar because of pressure from the emerging root tip. With this type of fracture a membrane, described by Martin and Watt (7) as the endosperm, ensheaths the root and later the hypocotyl to the point where they emerge from the seed coat. When the seed coat fails to rupture or ruptures at another point a gelatinous substance collects under this membrane especially in the region of the hypocotyl. It sometimes appears on the seed coat. This material was associated with 69% of the seeds that failed to germinate in the presence of *Pythium* and with only 11% of those that failed to germinate in its absence. The association of abnormal fractures in the seed coat with seed rotting may be a result of a previous action of the fungus on the seed or it may be because cracks are a contributing factor to seed rotting. The hypocotyl may fail to elongate because of the influence of the fungus on germination. In

such a case the seed coat may not rupture near the hilum scar but may rupture elsewhere because of imbibition of water by the seed. On the other hand, the cracks that result from imbibition or previous injuries to the seed coat may allow the fungus to influence the physiology of the germinating seed and prevent the elongation of the root and hypocotyl. In either case a substance apparently very nutritive to the fungus (indicated by a concentration of mycelium about such seeds) collects outside the embryo. Certain types of cracks in the seed coat that occur in seed scarification may predispose the seed to rot when they cause the seed coat to rupture away from the hilum scar during germination.

A stimulating effect of *Pythium* on germination has been noted. In some seed lots the presence of the fungus increases the number of seeds that sprout in the first 24 hours. In all seed lots germinating in the presence of the fungus, the seeds that have not sprouted after 72 hours have rotted (less than 0.01% of the seed will sprout after 72 hours). Seeds that are germinated under similar conditions without the fungus often do not sprout until after 150 hours. This indicates that the fungus can influence the physiology of the germinating seed and not kill the embryo but may actually stimulate it. However, if the seed does not sprout promptly the influence of the fungus on the germinating seed is lethal.

The genetic differences found between plants that accounted for differences in the amount of seed rotting in the seed they produced cannot, in most cases, be considered as due to a specific interaction of the organism and a gene or genes for resistance or susceptibility of the host. Rather it is due to characters of the seed-producing plant that influence seed development in the environment in which the plant is growing. The mature plant characters that influence seed development are probably resistance or susceptibility to certain diseases or adverse environmental conditions that are not expressed in the greenhouse so mature seeds from most greenhouse-grown plants are not likely to be susceptible to seed rotting. Greenhouse seed that was allowed to develop fully showed no appreciable amount of seed rotting, except in a few cases (Table 6), while seed produced on a large proportion of plants in the field was susceptible to seed rotting. Even though immature greenhouse-produced seed did give a differential response in the presence of *Pythium*, greenhouse-produced seed would not be satisfactory because it would not be practicable to collect large quantities of immature seed at the same stage of development. To take advantage of the inherent differences in plants in a sweetclover breeding program, it will be necessary to use field-produced seed to determine from the progeny the inherent character of the parent plant.

The testing of seed on moist sand containing mycelium of a pathogenic strain of *Pythium* can be useful in evaluating commercial lots of seed. The correlation between the percentage of seeds that germinate in this test and the emergence of seedlings in the field is much higher than the percentage of viable seeds, used by seed laboratories at the present time to evaluate seed lots, and emergence in the field.

It has not proved practical to protect sweetclover, alfalfa, and red

clover seed from rotting with fungicides. Buchholtz (2), Chilton and Garber (3), and Allison and Torrie (1) found that it is possible to increase total emergence by various seed treatments when the seed is planted in greenhouse soil. However, they found in field tests that seed treatments failed to result consistently in increased emergence. Any reduction in seed rotting through the development of resistant varieties will be a gain that has not been secured in any other way.

SUMMARY

The percentage of viable, scarified seeds that emerged as seedlings varied among seed lots of *Melilotus alba* and *M. officinalis* when planted in the field and in the greenhouse at Madison, Wis., in 1944 and 1945. Differences in soil temperature in the range of 7° to 22°C did not influence the percentage of emergence and the locations of seeds that failed to emerge were random.

Pythium debaryanum and *P. ultimum* proved to be pathogenic, but the entire range of pathogenic species of *Pythium* was not determined.

After seeds were planted in *Pythium*-infested soil for 72 hours, they could be placed in two classes. In the one, the seeds rotted before the hypocotyl began to elongate and in the other the hypocotyl elongated at least ½ cm. In the latter class some were invaded by the fungus, but this failed to stop elongation of the hypocotyl. The lack of gradations between the two groups suggests that seed rotting is independent of later invasion of the hypocotyl as occurs in damping-off. Further evidence for this is the lack of an association between the percentage emergence and the percentage of seedlings showing damping-off after emergence.

Viable immature seeds are more likely to rot than genetically comparable mature seeds.

When a seed coat is ruptured near the hilum scar the seed is not likely to rot in the presence of the fungus. Seeds that rot frequently have cracks elsewhere in their seed coats.

Inherent differences were found among plants in the amount of seed rotting found in their progenies. These differences were probably due to mature plant characters that influence seed development rather than to genetic factors for resistance or susceptibility to *Pythium* of the germinating seeds.

LITERATURE CITED

1. ALLISON, J. LEWIS, and TORRIE, J. H. Effect of several seed protectants on germination and stands of various forage legumes. Phytopath., 34:799–804. 1944.
2. BUCHHOLTZ, W. F. Influence of cultural factors on alfalfa seedling infection by *Pythium debaryanum*. Iowa Sta. Res. Bul. 296:569–592. 1942.
3. CHILTON, S. J. P., and GARBER, R. J. Effect of seed treatment on some forage legumes. Jour. Amer. Soc. Agron., 33:75–83. 1941.
4. COCHRAN, W. G. Statistical analysis of field counts of diseased plants. Jour. Roy. Stat. Soc., III:49–67. 1936.
5. ERICKSON, LAMBERT C. The effect of alfalfa seed size and depth of seeding upon the subsequent procurement of stand. Jour. Amer. Soc. Agron., 38: 964–973. 1946.

6. GRANDFIELD. C. O., LEFEBVRE, C. L., and METZGER, W. H. Relation between fallowing and damping-off of alfalfa seedlings. Jour. Amer. Soc. Agron., 27:800–806. 1935.
7. MARTIN, J. N., and WATT, J. R. The strophiole and other seed structures associated with hardness in *Melilotus alba* L. and *M. officinalis* Willd. Iowa Sta. Col. Jour. Sci., 18:457–468. 1944.
8. STEWART, F. C., FRENCH, G. T., and WILSON, J. K. Troubles of alfalfa in New York. N. Y. State Agr. Exp. Sta. Bul. 305:331–416. 1908.
9. WELCH, AARON. Pythium root necrosis of oats. Iowa Sta. Col. Jour. Sci., 19:361–399. 1945.

A Comparison of the Glass Electrode and Indicator Methods for Determining the pH of Organic Soils and Effect of Time, Soil-water Ratio, and Air-drying on Glass Electrode Results[1]

J. F. DAVIS AND KIRK LAWTON[2]

THE use of a set of several single indicators has been the accepted method (LaMotte-Morgan) for testing the reaction of muck soils for a number of years by members of the Soil Science Department of the Michigan Experiment Station. Recommendations regarding fertility practices on muck soils have been based on data obtained by this method which has proved to be a very accurate and valuable means of diagnosing problems pertaining to muck soils of the state. Recently, glass electrode assemblies in which the source of current is obtained from an electrical outlet rather than from the conventional battery type equipment has become available. It is the purpose of this paper to present the results obtained in a study relating to a comparison of the indicator and glass electrode methods of obtaining the pH of muck samples.

PROCEDURE

Fifty muck samples were collected at random in a series of muck soil extension meetings held during February and March. These samples were brought to the meetings by farmers for testing and subsequent soil treatment recommendations for crops to be grown. The samples ranged from well-decomposed mucks to those that were quite peaty in nature; and in moisture content they varied from those which were well dried to those which were brought in as a frozen mass directly from the field. The LaMotte-Morgan indicators[3] were used for making the pH determinations at the meetings. The samples selected for further study were placed in cellophane bags, assigned a number, and taken to the soil testing laboratory for pH determination by use of the glass electrode.

The following procedure was used in the work. A level tablespoon of soil (15 ml) was placed in a 50-ml beaker and 15 ml of distilled water added. The sample was then stirred for 1 minute and the pH determined immediately. A pH reading was again made on the same sample at the end of 15 minutes and at the end of 60 minutes, with thorough stirring prior to the time of taking each reading. From the 50 samples, 15 were selected for a study of the effect of soil-water ratios on the pH. Soil-water ratios of 1:0.5, 1:1, and 1:2.5 were investigated. In addition, 15 samples were air-dried and then the effect of this air-drying was investigated on the pH determined at the end of 1 minute and 15 minutes.

A 1:1 soil-water ratio was first used for the air-dry samples, but it was very difficult with some samples to get a consistency of the muck mixture mechanically suitable for reading with the glass electrode. In some cases the muck absorbed enough of the water so that the soil paste was actually too dry for efficient operation of the electrode. The apparent dryness of the sample increased with time, indicating that thorough wetting was not obtained after 1 minute. For this reason a 1:2 soil-water was used for the 15-minute reading of the air-dry samples.

[1]Contribution from the Soil Science Section of the Michigan Agricultural Experiment Station, Michigan State College, East Lansing, Mich. Authorized for publication by the Dierctor as Journal Article No. 875 N.S. Received for publication April 16, 1947.

[2]Associate Professor and Assistant Professor of Soil Science, respectively.

[3]Phenol red (7.0–8.6), brom thymol blue (6.1–7.7), chlor phenol red (5.1–6.7), brom cresol green (3.8–5.4), brom phenol blue (3.1–4.7).

This apparent drying out of the sample is explained by the observation that 1 minute is not sufficient time to allow for complete absorption of water by the dry muck particles. As the length of time increases, more water is absorbed by the dry particles so that the soil-water mixture actually appears drier as time elapses.

DISCUSSION AND RESULTS

The data obtained in the comparison of the indicator (LaMotte Morgan) and the glass electrode methods are reported in Table 1. It is obvious that a very close agreement exists between the results obtained by the two methods and, for all practical purposes, the methods are equally acceptable. Likewise, the results obtained at the end of 1, 15, and 60 minutes indicate very small variations due to the time elapsed between readings.

The lower pH limit of the indicators used is 3.1. In the case of samples 36 and 37, with respective pH readings of 2.85 and 2.35, accurate determinations, of course, were unobtainable. It should be

TABLE 1.—*A comparison of the glass electrode and indicator (LaMotte-Morgan) methods for determining the pH of muck soils.*

Sample No.	pH obtained				Sample No.	pH obtained			
	LaMotte-Morgan method	Glass electrode method*				LaMotte-Morgan method	Glass electrode method		
		1 min.	15 min.	60 min.			1 min.	15 min.	60 min.
1	6.1	5.90	6.00	6.00	26	5.9	5.60	5.60	5.60
2	7.2	6.90	7.00	7.00	27	5.6	5.75	5.75	5.75
3	4.7	4.55	4.55	4.50	28	5.9	6.10	6.10	6.10
4	4.6	4.45	4.50	4.40	29	6.5	6.55	6.55	6.55
5	4.1	3.70	3.75	3.70	30	6.9	6.80	6.80	6.80
6	5.9	5.90	5.90	5.85	31	7.8	7.40	7.35	7.35
7	7.0	7.45	7.40	7.35	32	3.8	3.20	3.20	3.15
8	6.9	6.75	6.80	6.75	33	4.6	4.25	4.25	4.20
9	7.0	7.05	6.95	7.15	34	6.3	6.15	6.15	6.05
10	6.3	6.20	6.15	6.20	35	6.1	6.00	6.00	6.00
11	3.9	3.80	3.80	3.85	36	−3.0†	2.85	2.85	2.85
12	6.2	6.05	6.00	6.00	37	−3.0†	2.35	2.30	2.30
13	5.1	4.75	4.65	4.65	38	5.2	5.20	5.20	5.20
14	6.0	5.80	5.75	5.75	39	5.4	5.30	5.30	5.30
15	5.8	5.75	5.70	5.75	40	6.7	6.50	6.50	6.50
16	5.5	5.55	5.50	5.50	41	6.8	6.60	6.60	6.55
17	6.4	6.30	6.25	6.25	42	5.3	5.35	5.35	5.30
18	6.1	6.25	6.25	6.20	43	5.5	5.40	5.35	5.25
19	4.8	5.00	5.00	5.00	44	6.4	6.65	6.60	6.60
20	4.6	4.65	4.60	4.65	45	6.7	6.85	6.80	6.75
21	5.0	5.20	5.20	5.15	46	6.8	6.70	6.65	6.60
22	7.0	7.20	7.15	7.15	47	6.9	6.75	6.75	6.70
23	7.3	7.50	7.50	7.45	48	5.4	4.95	4.95	4.90
24	6.3	6.20	6.20	6.20	49	5.2	5.30	5.25	5.20
25	5.7	6.15	6.15	6.15	50	5.8	5.65	5.60	5.55

*Minutes refer to time lapsed after distilled water was added to the muck in 1:1 soil-water ratio and the pH reading made with glass electrode.

†The true readings here were recognized to be below the limits of the indicator at time the samples were tested.

realized, however, that for practical purposes, the reading obtained from the indicator would be adequate.

Very little effect on pH readings can be ascribed to variations of the soil-water ratio within the limits of the work, as indicated by the data reported in Table 2. In general, a slightly higher value was obtained with the 1:2.5 ratio than with either the 1:0.5 or 1:1 ratios. It should be pointed out that the differences in Table 2 may be due to two sources, namely, possible variation in pH in different parts of the sample and differences in the soil-water ratio, since different soil aliquots of the same sample were used in making up the various ratios. From the practical standpoint, however, there is a sufficiently close agreement between the readings, so that either of the soil-water ratios could be used.

In Table 3 are presented data showing the effect of air-drying on the pH readings. Apparently no practical differences arise between pH readings taken of moist samples as collected and these same samples after air drying and re-wetting. An indication of the variability in moisture contents of field samples brought in by farmers for testing may be noted in Table 3. The range in moisture contents based on air-dry weight is between 86.8 and 383%. With this wide variability of moisture contents, it is fortunate that the soil-water ratio has very little effect on the pH reading.

TABLE 2.—*The effect of varying the soil-water ratio on the pH values of some muck soils as determined with the glass electrode.**

Sample No.	Soil-water ratio		
	1:0.5	1:1	1:2.5
1	6.00	6.00	6.30
3	4.55	4.55	4.60
5	3.70	3.75	3.80
6	5.85	5.90	6.00
11	3.70	3.80	4.00
12	5.95	6.00	6.15
16	5.45	5.50	5.70
21	5.20	5.20	5.30
23	7.20	7.50	7.35
24	6.15	6.20	6.30
31	7.30	7.35	7.50
32	3.25	3.20	3.40
36	2.75	2.85	2.90
45	6.60	6.80	6.80
47	6.70	6.75	6.75

*pH readings taken after 15 minutes.

During the late winter and early spring seasons, it is found that well-decomposed organic soil samples are highly dispersed and that the dispersed soil particles interfere somewhat with the accuracy of pH readings made by use of an indicator. This situation, however, is not a factor with pH readings obtained by the glass electrode. The glass electrode method is the more rapid of the two, and this factor is of primary importance in those cases in which a large number of

TABLE 3.—*The effect of air-drying organic soils on the pH as measured by the glass electrode.*

Sample No.	Moisture, %*	pH after 1 minute		pH after 15 minutes	
		Wet (1:1)†	Dry (1:1)	Wet (1:1)	Dry (1:2)
1	112.0	5.90	5.75	6.00	5.85
3	251.0	4.55	4.40	4.55	4.45
5	267.0	3.70	3.50	3.75	3.65
6	206.0	5.90	5.85	5.90	5.90
11	199.0	3.80	3.65	3.80	3.70
12	239.0	6.05	5.85	6.00	5.90
16	104.0	5.55	5.35	5.50	5.50
21	124.0	5.20	5.10	5.20	5.15
23	86.8	7.50	7.10	7.50	7.20
24	133.0	6.20	6.00	6.20	6.10
31	156.0	7.40	7.40	7.35	7.50
32	282.0	3.20	3.40	3.20	3.40
36	258.0	2.85	2.90	2.85	2.90
45	322.0	6.85	6.70	6.80	6.70
47	383.0	6.75	6.70	6.75	6.65

*Moisture percentage based on air-dry weight.
†Numbers in parentheses refer to soil-water ratios.

samples are collected at an extension soil-testing meeting. As the season progresses, the condition of the soil, through alternate wetting and drying tends to become more flocculated and the accuracy of a pH reading made by the use of an indicator is not materially affected. In an extension soil-testing meeting, small paper cups may be used with the glass electrode procedure to reduce the time required for making the tests by eliminating the need for washing glassware.

It is obvious that the use of indicators for testing samples in the field is the more satisfactory method of the two. No source of electric current is required, and the pH of samples may be determined right on the spot in question. Many times the pH of the soil sample correlates with the appearance of the crop and is the most important single diagnostic aid in determining the casual agent for a number of specific nutritional troubles.

SUMMARY

A comparison of the glass electrode and indicator (LaMotte-Morgan) methods for obtaining the pH of muck was made on 50 samples collected at random from soil-testing extension meetings held during February and March. The effects of time elapsed between mixing the soil and water and obtaining the pH readings, soil-water ratios, and air-drying on pH readings were investigated.

Data obtained indicate a close agreement between pH readings obtained by the indicator and glass electrode methods. Due to the high buffer capacity of the muck, factors of time elapsing between mixing the muck sample with water and subsequent recording of the pH reading, the soil-water ratios within the limits of the work, and air-drying of the samples do not materially affect the pH reading of the sample.

It is concluded from the data presented that an accurate pH reading of muck may be obtained with a glass electrode when a 1:1 soil-water ratio based on a volume relationship is used.

Pasture or Woodland?[1]

A. C. ARNY[2]

OF the 5,383,000 acres on farms in Minnesota classified as woodland in the 1935 census on the basis of having value as wood or timber, 77.4% was reported as pastured. In the 25 counties in the southeastern and south central parts of the state where practically all of the country side is in farms 83.4% of the acreage classified as woodland was reported as used for grazing. In the northeastern and north central border counties and in others adjoining them to the south, the percentage of land in farms is relatively low, averaging less than 20. In these counties there are extensive acreages of cut-over land covered largely with second growth timber and brush and large swamp areas. These areas are largely ungrazed.

Reported yields of pasturage obtained prior to 1937 from permanent woodland pastures in other states were very low as compared with yields from nearby open areas. Observations in permanent pastures in Minnesota appeared to confirm these findings. However, it was thought important to check these observations and in so doing obtain local data which would be useful in the discussion of the management of permanent pastures.

LITERATURE REVIEW

Day and Den Uyl (4)[3] studied natural reproduction in progressive stages of degeneration of farm woodlands due to grazing. They found that where the stands of trees provided less than 50% crown density and a complete grass cover had formed, satisfactory natural regeneration of the trees could not be expected. They concluded that while the grazing value of these woodlands was low, it was probably as great or greater than the anticipated returns from forest products considering the length of time and expenditures necessary to bring areas of this kind back to productive woodland conditions.

Chandler (3) compared prevailing soil and moisture conditions in grazed and ungrazed areas in New York woodlands in the open park and final stages. The amount of light penetrating the forest canopy in the ungrazed areas averaged only 3.03% full sunlight as compared with 21% under the grazed conditions. He found that the organic matter and moisture content of the soil were higher in the ungrazed than in the grazed areas. Air temperature and humidity determined 1 foot above the soil surface and soil temperature taken 1 inch below the soil surface were higher in the grazed than in the ungrazed areas.

Den Uyl and Day (5) during the period 1931–34 grazed yearling steers at the rates 2, 4, and 6 acres per animal in woodlands with about 100 oak and hickory trees ranging from about 2 to 20 inches in diameter. Two acres per animal provided only maintenance rations during the early part of the 1931 and 1932 seasons. The last year, the very dry year of 1934, it was not considered suitable for any grazing. Four acres per animal provided fair gains the first year up to about September 1, the second year only slight gains were made at the beginning of the season, and no gains were made the last two years. Six acres per steer resulted in fair gains up to September 1 the first year and to the middle of August the second year. The third year this area produced only a maintenance ration until about August 1. In the season of severe drouth (1934) this area did not provide

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[3]Figures in parenthesis refer to "Literature Cited", p. 732.

a maintenance ration, while the steers on open rotation pasture made good gains up to the middle of August.

Northern Minnesota cut-over lands provided adequate feed for 49,486 cattle shipped in from other parts of the state during the severe drouth of 1934 (10). The period of grazing was from July 27 to October 1.

Where satisfactory legume stands were obtained in renovating southeastern Minnesota permanent pastures, increases in yields averaged 76% (2).

From an Ohio wooded area completely covered with a stand of grass where light ranged from 10 to 24% of that in the open, Welton and Morris (11) obtained a 2-year average yield of 743 pounds pasturage on a dry matter basis compared with 2,195 pounds from a nearby and comparable open area. Nearly 3 acres of the woodland pasture were required to produce as much pasturage as 1 acre in the open. On a dry weight basis, the grass grown in partial shade was somewhat higher in protein but lower in carbohydrates than that grown in the open. They concluded that their results did not support the contention of farmers that the feed obtained from woodland pastures more than offsets the injuries caused by grazing these areas.

Roberts (9) shaded artificially five species of grasses. Analysis of four of the five species showed increased crude protein and reduced carbohydrate percentages for the shaded grasses. Wilson (12) stated that 1 acre of pasture in the open should produce as much pasturage as 4 acres under shade. He advised the use of the best land for grazing and crop production and that not desirable for grazing and crops be utilized for forestry.

Ahlgren, Wall, Muckenhirn, and Sund (1) obtained yields of pasturage per acre on a dry matter basis over the 5-year period 1940–45 of 276 pounds from wooded and 1,453 pounds from open, unimproved, permanent Wisconsin pastures located on 15 to 35% north slopes. One acre in the open produced as much pasturage as 5.2 wooded acres. They observed that diary cattle preferred the pasturage grown in the open to that grown in the woodland.

Woodward (13) found that pastures need to yield at the rate of 2,500 pounds per acre of rapidly growing grass on an 80% moisture basis in order that dairy cows that produced 25 pounds or more of milk daily could readily graze their fill. This would be a yield of 500 pounds dry matter or 0.29 ton per acre on a 15% moisture basis.

Data collected over the period 1931–36 on 96 Vermont farms (6) showed a value per acre of $2.05 from grazed woodlands from wood products used on the farms or sold. The portions of these woodlands where maple trees predominated yielded sirup valued at $11 per acre.

Records from 89 ungrazed woodlands in Iowa, Michigan, Minnesota, and Ohio (7) during the period 1940–45 showed net incomes per acre varying from $8.50 for the 25 highest to $1.92 for the 39 medium and –$.23 for the 25 lowest. Income from maple sirup constituted part of the returns per acre from nearly one-half of the woodlands in the highest income group. The average annual net income per acre for the 89 woodlands was $3.

METHODS OF PROCEDURE

Yields and other data were obtained in permanent pastures in two areas in Minnesota to determine (a) the effect of the shade of 10 to 15 oak trees per acre 8 to 10 inches in diameter at breast height, and (b) the effect of the shade of stands of trees thick enough to serve as woodlots if not used for grazing.

To determine the effect, if any, of the occasional tree, five representative pastures with 10 to 15 oaks varying from 8 to 10 inches in diameter at breast height were selected in Ramsey County in the east-central part of the state. In each pasture a wire cage 4 by 4 feet square and 18 inches high was set in the area shaded at mid-day by each of six trees and the same number of cages was set in adjacent nonshaded areas. On four of these farms the soil had been classified as Bradford loam and the fifth as Hubbard sandy loam.

To determine the effect of shade of average stands of trees on yield and composition of pasturage, four representative unimproved permanent pastures were selected in the southeastern part of the state. These pastures had been grazed for many years. The pastures on farm Nos. 1 and 2 as listed in Tables 3 to 5 were located in Fillmore County near Spring Valley and those listed as Nos. 3 and 4 in Winona County. The soils on these farms had been classified as Clinton and

Dubuque. In each of these pastures typical wooded areas were selected and six cages set in the shade and six in adjacent open areas.

Growth of the vegetation under the cages was cut as often during the grazing season as it averaged 5 to 6 inches in height. At each cutting the cages were moved to new locations from which the vegetation had been cut at about 1 inch height. In September and October the growth was harvested even though it had not reached the predetermined height of cutting. The harvested material was oven dried and yields calculated on the dry matter and 15% moisture basis. All yields are reported on the 15% moisture basis. Estimates were made of the botanical composition of harvested material.

In the wooded and open areas in the four permanent pastures in the southeastern part of the state, light meter readings were made. The meter readings were made at 9 a.m., 2 p.m., and 4 p.m. on the same clear day at intervals throughout the grazing season and the results averaged. The meter was held 3 feet above and at right angles to the growth under the cages. Tree counts were made on a representative tenth-acre wooded area in each pasture and diameters determined at breast height.

All of the areas, both open and wooded, were covered with a fairly evenly distributed pasture vegetation largely Kentucky blue, *Poa pratensis*, with varying amounts of white clover, *Trifolium repens*, and weeds.[4]

With the exception of a few areas in each pasture, the land, had it been cleared of trees, was as suitable for tillage as other land growing harvested crops on these farms.

The work on the four farms in the southeastern part of the state was done in cooperation with the Soil Conservation Service.

EXPERIMENTAL RESULTS

Yields of pasturage from under the scattered oak trees and adjacent open areas in Ramsey County were determined for five permanent pastures in 1937 and for two in 1939. These yields have been summarized in Table 1.

TABLE 1.—*Yields of pasturage in tons per acre from under scattered oak trees and adjacent open areas in permanent pastures on farms in Ramsey County.*

Pasture No.	Open	Under trees	Average
	Yields in 1937		
1	1.01	1.32	1.17
2	1.11	0.90	1.00
3	1.18	1.48	1.33
4	0.79	0.97	0.88
5	0.93	1.21	1.07
Average........	1.07	1.25	1.16
	Yields in 1939		
1	0.75	0.64	0.70
2	0.98	1.00	0.99
Average........	0.87	0.82	0.85

In 1937 yields from the areas under the trees were slightly higher from four out of the five pastures than from the nearby unshaded areas. No yields were determined for the under-tree area in 1938.

[4]The term Kentucky "blue" is used here rather than the accepted form of "bluegrass" at the author's behest.

In 1939, the average yields for the open and shaded areas (two pastures) were similar.

In 1939 the average protein content of the pasturage from the open areas of pasture No. 1 was 15.5% and from under-the-tree areas 13.1%. There was practically no white clover in this pasture that year. In pasture No. 2 there was considerable white clover in patches here and there apparently not influenced by the trees. The average protein content of the pasturage from the open areas was 16.8% and from the under-the-tree areas 16.5%.

These limited data appeared to warrant the conclusion that the shade of the scattered oak trees in these permanent pastures had little or no effect on yield or composition of the pasturage produced.

Data obtained from the open and adjacent wooded areas in the four permanent pastures in Fillmore and Winona counties in the southeastern part of the state have been brought together in Tables 2 to 5, inclusive.

Numbers of the different species of trees per acre with their average diameters in inches for the wooded areas in the four pastures have been summarized in Table 2.

TABLE 2.—*Kinds, numbers per acre, and average diameters of trees on the grazed wooded areas in the permanent pastures on two farms in Fillmore County and two in Winona County.*

Kind of tree	Pasture							
	No. 1		No. 2		No. 3		No. 4	
	No.	Diameter, in.	No.	Diameter, in.	No.	Diameter, in.	No.	Diameter, in.
White and red oaks	260	7.3	30	7.1	31	11.7	170	8.5
Hard maple	10	3.3	10	8.6	—	—	—	—
Basswood	—	—	230	8.6	—	—	—	—
Ash	—	—	20	7.7	—	—	—	—
Elm	—	—	30	8.7	—	—	—	—
Hickory	—	—	—	—	4	9.3	7	4.5
Butternut	—	—	—	—	6	9.8	—	—
Ironwood	50	2.3	—	—	—	—	—	—
Aspen	10	2.2	—	—	—	—	—	—
White birch	—	—	—	—	—	—	27	2.6
Total	330		320		41		204	

The two Fillmore County pastures, Nos. 1 and 2, had the largest number of trees per acre and most of them averaged well above 7 inches in diameter. Each of these two pastures had 70 trees per acre 12 to 14 inches in diameter. Of the two Winona County wooded areas, that in pasture No. 3 had the lowest number of trees, but all species averaged above 9 inches in diameter. In pastures Nos. 1 and 4, the wooded areas contained some young trees. There was practically no brush and no tree seedlings on any of the four wooded areas.

Average light percentages in the wooded as compared with nearby open areas in the four permanent pastures have been brought together in Table 3.

TABLE 3.—*Average percentage of light in the wooded as compared with 100 for the adjacent open areas at 9 a.m., 2 p.m., and 4 p.m. in the four permanent pastures in southeastern Minnesota.*

Pasture No.	Percentage light in wooded area with open area at 100			
	9 a.m.	2 p.m.	4 p.m.	Average
1	16	32	30	26
2	11	21	5	13
3	28	39	30	32
4	8	21	8	12
Average....	16	28	19	21

Somewhat more light reached the pasture plants in pasture No. 3, with only 41 fairly large trees per acre, than in the other three. Least light reached the pasture plants in pasture No. 4, with a lower number of both large and small trees, than in pasture No. 1. The undergrowth in pasture No. 4 was white birch, while in pasture No. 2 it was ironwood and aspen. The range in the percentage of light reaching the pasture plants in the wooded area of each of the four pastures compared with 100 for the open was not far different from the 10 to 24% reported by Welton and Morris (11) for the wooded area in an Ohio pasture. The average of 21% of full sunlight reaching the pasture plants in the wooded areas of the four pastures compared with 100 for the open is the same as that found by Chandler (3) for the grazed, wooded areas in 18 New York pastures.

Yields of pasturage from the open and wooded areas in two of the pastures for 1938 and 1941 and in all four in 1939 and 1940 with yields of the wooded in percentage of those from the open have been brought together in Table 4.

The yield of pasturage from the open area in each pasture was much higher than from the adjacent wooded area every season that determinations were made. In 1938, with rainfall above normal, the open areas of pastures Nos. 3 and 4 averaged the exceptionally high yield of 2.29 tons per acre. This was over a ton per acre higher than they averaged either of the two following years when rainfall was near normal. While the yields from the adjacent wooded areas in these two pastures was higher in 1938 than they averaged in 1939 and 1940, the actual increase due to the unusually heavy rainfall in 1938 was only 0.08 and 0.21 ton per acre, respectively.

On the basis of the average yields obtained from these four representative Minnesota permanent pastures, 4.5 acres of wooded land were required to yield the amount of pasturage that 1 acre in the open produced. This was half again as many acres of woodland pasture as the 3 acres required to produce as much pasturage as 1 acre in the open in the Ohio test (11) and midway between the 4.0 and 5.2

TABLE 4.—*Annual yields of pasturage in tons per acre from open and adjacent wooded areas in four permanent pastures on farms in southeastern Minnesota with yields from the wooded pasture in percentage of the yields from the open areas.*

Pasture No.	1938	1939	1940	1941	Average
			Open		
1	—	0.71	1.22	0.87	—
2	—	0.92	0.88	1.45	—
3	2.37	1.38	1.39	—	—
4	2.21	1.12	0.59	—	—
Average......	2.29	1.03	1.02	1.16	1.38
			Wooded		
1	—	0.49	0.43	0.17	—
2	—	0.13	0.35	0.47	—
3	0.35	0.28	0.25	—	—
4	0.34	0.15	0.11	—	—
Average......	0.35	0.26	0.29	0.32	0.31
			Wooded in Percentage of Open		
1	—	69.0	35.2	19.5	—
2	—	14.1	39.8	32.4	—
3	14.8	20.3	18.0	—	—
4	15.4	13.4	18.6	—	—
Average......	15.1	29.2	27.9	26.0	24.6

acres reported for Wisconsin (1, 12). This great advantage in production of pasturage per acre annually by the open as compared to the wood pasture areas can be further increased economically from 50 to 100% by renovation with and without fertilization (1, 2).

Comparison of the open and wooded areas on the basis of yield does not take into consideration costs of production. On a dollar and cents basis, the average yields of 1.38 and 0.31 tons of pasturage per acre were worth $27.60 and $5.27, respectively, gross value. Deducting $2 per acre per year for interest, taxes, and fencing charges, the net values of $25.60 and $3.27 were obtained. These values were arrived at by taking the digestibility of air-dry, rapidly growing, young grass-legume pasturage as 82% of that of farm grains (8) and using $1 per hundred weight as the average price on farms of small grains and corn in Minnesota during the period 1938–41. On the basis of net income the annual return from 1 acre of the open pasture was equal to that on 7.8 acres of the wooded pasture.

While a few of the ungrazed woodlots, particularly those producing maple sirup, were reported as averaging as high or higher in net income per acre as the $25.60 averaged by the open areas in these southeastern Minnesota pastures, the average for the 25 highest income woodlands was $8.50 (7).

The average annual net income of $3.27 per acre from pasturage obtained from these southeastern Minnesota woodlands was only

slightly higher than the $3.00 average reported for the 89 ungrazed woodlands in this same general territory (7).

The average yields in tons per acre of pasturage from the open and wooded areas by months for the grazing season have been brought together in Table 5.

TABLE 5.—*Four-year average monthly and seasonal yields of pasturage in tons per acre from open and adjacent wooded areas in permanent pastures on four farms in southeastern Minnesota.*

Location	May	June	July	Aug.	Sept.	Oct.	Total
Open	0.32	0.37	0.26	0.25	0.12	0.06	1.38
Wooded	0.13	0.09	0.04	0.03	0.01	0.01	0.31
Difference	0.19	0.24	0.22	0.22	0.11	0.05	1.07

The average yields of 0.32 and 0.37 ton per acre of pasturage from the open areas in the four pastures for May and June were somewhat higher than the 0.29 ton found by Woodward (13) to be necessary for high-producing dairy cows rapidly to gain their fill. In July and August the yields were somewhat higher than the longer time averages of 0.22 and 0.16 ton, respectively, due to heavier than average yields in 1938 (2). Even so, the yields were somewhat lower than required for high-producing dairy cows. Yields in September and October were very low in comparison with those for the months preceding.

Average yield of pasturage per acre from the wooded areas for May and June were only 0.13 and 0.09 tons, respectively. Yields for September and October were negligible. At no time during the grazing season would dairy cows producing 25 pounds or more of milk daily be able to obtain adequate nutrients from grazing in these wooded areas exclusively or in pastures where woodlands constitute a high percentage of the total.

The botanical composition of pasturage from the open areas averaged 68% Kentucky blue, 26 % white clover, and 7% weeds of various kinds. Under the trees, the pasturage averaged 74% Kentucky blue, 6% white clover, and 19% weeds.

The protein of the pasturage from the open areas averaged 16.8% as compared with 12.4% for that from under the trees. This difference in protein content was undoubtedly due largely to the higher percentage of white clover in the pasturage from the open areas. The average yield per acre of protein in the pasturage from the open areas was 305 pounds, or 5 times as much as the 60 pounds per acre averaged by the wooded areas.

DISCUSSION

Using the information now available, what are the best procedures in the management of permanent pastures in Minnesota and other states with similar soil and climatic conditions?

On a large majority of farms permanent pastures do not provide adequate feed for the livestock even during May, June, and July,

their period of greatest productivity. The quickest way to obtain increased pasturage is to renovate part of the acres of the open areas in these pastures. Increases of from 50% to 100% in yield obtained from this procedure pay for the expense involved and a handsome profit in addition (1, 2).

One or more forms of forest products, lumber for repairs or for new buildings, fenceposts, firewood, are needed now on practically every farm and will continue to be needed in the future. These products produced on the farms where they are used and their values computed at prices they would cost if purchased at retail prices usually will result in higher than average income per acre from woodlands. Therefore it appears advisable to fence off and keep all livestock out of 5 to 8 acres per farm, more or less depending on needs, of good woodland as a continual source of these products. Woodland on slopes too steep to work to advantage with farm machinery and on rough and stony areas should be left in woods even though the yield of forest products from them will be low.

For maximum returns per acre it appears advisable to clear completely a number of acres of the land best suited either for pasture or for the raising of harvested crops. The forest products from these clearings would supply the farm needs while the fenced woodlots were improving and for sale as satisfactory prices could be obtained. The acreage advisable to clear completely will naturally vary greatly with the character of the land. In the two counties in southeastern Minnesota where the yields of pasturage were determined, the average acreage of woodland per farm is 30 and 50, respectively. An average of from 10 to 15 acres per farm, if that amount of good land is available, might be considered for the first clean cutting in these counties.

By grazing the other wooded areas, there would be income per acre for a few years from both pasturage and forest products. As the trees on these areas suitable for pasture or crop land reached the desired dimensions for harvesting and were removed, the income per acre would increase until it reached that of open pasture or crop land.

SUMMARY

1. Yields of pasturage from areas in the shade of occasional oak trees at noon in permanent pastures did not differ significantly from those in adjacent open areas.

2. Open areas in permanent pastures in two counties in southeastern Minnesota averaged 1.38 tons of pasturage having a net computed income value of $25.60 as compared with an average of 0.31 ton with a net computed income value of $3.27 from adjacent wooded areas. One acre of the open pasture was equal to 4.5 acres of the adjacent wooded area in the production of pasturage and to 7.8 acres when compared on the net income basis.

3. The open pasture on these farms produced ample feed during May and June for dairy cows producing 25 pounds of milk daily rapidly to gain their fill. During no month in the grazing season did the adjacent wooded areas produce adequate pasturage for high-producing dairy cows.

4. The protein content of the pasturage from the open areas averaged 16.8% protein compared to 12.4% for that from the adjacent woodlands. This difference was probably due to the higher percentage of white clover in the pasturage from the open areas.

5. The open areas produced pasturage containing 305 pounds protein per acre which was five times the 60 pounds in the pasturage per acre of woodland.

LITERATURE CITED

1. AHLGREN, H. L., WALL, M. L., MUCKENHIRN, R. J., and SUND, J. M. Yields of forage from woodland pastures on sloping land in southern Wisconsin. Jour. Forestry, 44:709–711. 1946.
2. ARNY, A. C. Trials show way to higher yields from permanent pastures. Minn. Farm and Home Science, 3:4, 5, and 15. 1946.
3. CHANDLER, ROBERT F. The influence of grazing upon certain soil and climatic conditions in farm woodlands. Jour. Amer. Soc. Agron., 32:216–230. 1940.
4. DAY, R. K., and DEN UYL, D. The natural regeneration of farm woods following the exclusion of livestock. Purdue Univ. Agr. Exp. Sta. Bul. 368:1–48. 1932.
5. DEN UYL, D., and DAY, R. K. Woodland livestock carrying capacities and grazing injury studies. Purdue Univ. Agr. Exp. Sta. Bul. 391:1–16. 1939.
6. HITCHCOCK, J. A. The grazing of maple sugar orchards. Vt. Agr. Exp. Sta. Bul. 414:1–14. 1937.
7. LOCKE, STANLEY S. Income from farm woodland. Jour. Forestry, 43:725–27. 1945.
8. MORRISON, F. B. Feeds and Feeding. Ithaca, N. Y.: Morrison Publishing Co. Ed. 20. 1938.
9. ROBERTS, E. N. Wyoming forage plants and their chemical composition studies. Wyo. Agr. Exp. Sta. Bul. 146:35–90. 1926.
10. THOMPSON, M. J. A grazing adventure in northern Minnesota. Mimeographed final report of Minnesota Emergency Pasturage Project, Northeast Exp. Sta., Duluth. July 23–Dec. 31, 1934.
11. WELTON, F. A., and MORRIS, V. H. Woodland pastures. Ohio Agr. Exp. Sta. Bimonthly Bul., 136:3–8. 1929.
12. WILSON, F. G. The farm timber lot. Wis. Agr. Exp. Sta. Bul. 407:1–31. 1929.
13. WOODWARD, T. E. The quantities of grass that diary cows will graze. Jour. Dairy Sci., 19:347–357. 1936.

Note

FIELD TEST FOR AVAILABLE PHOSPHATE IN CALCAREOUS SOILS

QUICK chemical soil tests have come into extensive use during the past few years. These tests are designed for use in the field by persons with little or no scientific training but are also useful to agronomists for diagnosing the fertility, in the field, with a minimum of testing equipment. With the possible exception of pH tests, phosphate tests probably rate the highest in number of quick tests made throughout the United States. The various recommended tests employ extracting solutions which are in general of two types, *viz.*, strong solutions of a weak acid, usually acetic, highly buffered with its sodium salt; or weak solutions of a strong acid, usually nitric or sulfuric, slightly buffered.

Neither of these types is suitable for calcareous soils. In fact there is no quick field test for phosphate which has an acceptable value for such soils. In general, the quick test solvents are buffered at too low a pH for calcareous soils. Even when modified acetate buffer solutions of pH 6.0 to 6.5 are used on these calcareous soils, the tests show an abundance of available phosphate for soils which are known to be deficient.

Some years ago the investigations at the Arizona Agricultural Experiment Station indicated a need for an extracting solution which is weaker than the dilute acids used for the determination of available phosphate yet of greater solvent property than distilled water. Carbonic acid was found to fulfill this requirement and it has been continuously employed for 15 years in our laboratory for the routine determination of available phosphate in Arizona calcareous soils.[1]

The use of carbonic acid as a means of distinguishing between "active" and "dormant" phosphate in soils was first proposed by Daubeny in 1845.[2] Thus, it is probably the first of many solvents that have been proposed for determining the availability of soil phosphate. More recently it has been used by Dirks and Scheffer[3] and by Ensminger and Larson, [4] as well as our own laboratory. Thus far the use of carbonic acid has been limited to laboratory analyses because of the equipment needed, principally a source of carbon dioxide.

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[1]McGeorge, W. T. Factors influencing the availability of native soil phosphate and phosphate fertilizer in Arizona soils. Ariz. Agr. Exp. Sta. Tech. Bul. 82. 1939.

[2]Daubeny, C. G. B. Memoirs on the rotation of crops and on the quantity of inorganic matters abstracted from the soil by various plants under different circumstances. Roy. Soc. (London) Phil. Trans., 135:179. 1845.

[3]Dirks, B., and Scheffer, S. The carbonic acid-bicarbonate and water extracts for determining the phosphoric acid requirements of soils. Landw. Jahrb., 71:74. 1930.

[4]Ensminger, L. E., and Larson, H. W. E. Carbonic acid soluble phosphorus and lime content of Idaho soils in relation to crop response to phosphate fertilization. Soil Sci., 58:253. 1944.

Equipment is now available which permits the use of carbonic acid in the field as a quick test. For a supply of carbonic acid a "Sparklet" syphon is used. This syphon holds 1 quart of water and is equipped with an attachment by which it can be easily charged from small cartridges of liquid carbon dioxide. It has been tested on a large group of Arizona calcareous soils containing a wide range of available phosphate content. The equipment is shown in Fig. 1.

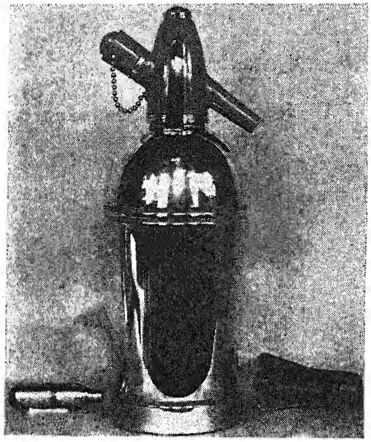

FIG. 1.—Sparklet syphon showing liquid CO_2 cartridge, left, and instrument for charging on right.

The quick test for available phosphate as developed in this laboratory is essentially as follows: Five grams of soil, approximately a teaspoonful, are placed in a 100-ml Nessler tube or similar tube, CO_2-charged water from the sparklet is added to the 100 ml mark. The whole is then shaken for 1 minute, filtered into a second Nessler tube to the 50 ml mark, and this filtrate used for the colorimetric phosphate test. From this point the procedure and reagents are the same as used in other field tests for phosphate. The reagents are ammonium or sodium molybdate solution and stannous chloride (or tin rod) which are regularly used in the Deniges test.

The ratio of 5 grams soil to 100 ml of CO_2-charged water is important. This ratio was selected after a study of the range in color intensity obtained with a number of soil: solvent ratios and using a group of soils which varied from 2 to 53 p. p. m. phosphate. This 5:100 ratio yields a color gradient that can be used and analyzed by comparison with the color charts which are a part of the Purdue and LaMotte test kits.—W. T. MCGEORGE AND G. A. PEARSON, *Department of Chemistry and Soils, Arizona Agricultural Experiment Station, Tucson, Ariz.*

Agronomic Affairs

ANNUAL MEETINGS OF AMERICAN SOCIETY OF AGRONOMY AND SOIL SCIENCE SOCIETY TO GET UNDER WAY MONDAY, NOVEMBER 17

As reported in the July issue of the JOURNAL, the dates for the annual meetings have been advanced to November 17 to 20 inclusive,instead of November 18 to 21, as originally scheduled. The program for Monday, November 17, will include registration and sectional meetings of the various Divisions instead of just a special fertilizer session as previously announced. The general program of the Society will be held Wednesday morning, November 19, and the joint banquet of the American Society of Agronomy and the Soil Science Society will be Wednesday evening. Further details will be announced as soon as they are available. All sessions of the American Society of Agronomy and the Soil Science Society will be held in the Netherland Plaza Hotel in Cincinnati, Ohio.

1947 MEETING OF WESTERN BRANCH

The Western Branch of the American Society of Agronomy held its annual summer meeting at Colorado A. & M. College, Fort Collins, Colorado, July 9 to 11, 1947. The program consisted of a joint one-day session with the Alfalfa Improvement Conference, Western Group, and one-half day sessions on soils and irrigation, cereal breeding, forage crops, and a trip to the Agronomy Farm.

Officers elected for the ensuing year included Doctor O. J. Kelley, Logan, Utah, President; Doctor R. H. Bamberg, Bozeman, Montana, Vice President; and E. J. Kreizinger, Pullman, Washington, Secretary.

The 1948 summer meetings will be held jointly at the State College of Washington, Pullman, Washington, and the University of Idaho, Moscow, Idaho.—RALPH M. WEIHING, *Secretary*.

NEWS ITEMS

RICHARD A. HOUGLAND is now employed as Agronomist by the Baker Castor Oil Company at Brawley, Calif. Mr. Hougland had been employed by the Forest Service and the Soil Conservation Service prior to his enlistment in the U. S. Naval Reserve as an Ensign. His military service was followed by employment in the Veterans Administration where he assisted in the Agricultural Training Program. His present duties are concerned with the research and production program of the Baker Castor Oil Company on castor beans as it applies to the irrigated Southwest.

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THE CHILEAN NITRATE EDUCATIONAL BUREAU announces publication of the seventh supplement to the third edition of the "Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition." It contains 963

abstracts, which include 108 crops and 45 elements. There are 1,202 authors listed. Complete indices are provided, i.e., author, element, botanical, and animal nutrition. For further information write Chilean Nitrate Educational Bureau, Inc., 120 Broadway, New York 5, N. Y.

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G. J. Callister, for the past five and a half years with the Fertilizers Administration of the Canadian Government, has been appointed Chairman and Secretary of the Committee on Fertilizers of the International Emergency Food Council. Upon expiration of this emergency work, he will act as Fertilizer Specialist for the Food and Agriculture Organization of the United Nations, with headquarters in Washington, D. C.

—A—

According to *Science*, Doctor George W. Snedecor, Director of the Iowa State College Statistical Laboratory since its establishment in 1933 and a member of the mathematics staff since 1913, retired from administrative duties July 1. He will continue as Professor of Statistics and as consultant to the Laboratory.

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According to newspaper accounts, on September 1st, Doctor H. R. Albrecht will succeed Doctor H. K. Wilson, now on leave, as head of the Department of Agronomy, Pennsylvania State College. He has been with the Purdue University Agricultural Experiment Station for the past several years.

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Doctor Robert Q. Parks of the Division of Soils, Fertilizers, and Irrigation, U. S. Dept., of Agriculture, who has been in charge of the Division's Soil Management Research in the Cotton Belt, was transferred on July 1 from Auburn, Ala., to the Plant Industry Station, Beltsville, Md., to take charge of the Division's soil management research carried on in the humid and dry land regions and under irrigation. Doctor Robert W. Pearson has been appointed to the position vacated by Doctor Parks. Doctor Pearson has been associated with the Alabama Agricultural Experiment Station since his return from military service in 1941.

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According to *Science*, the Imperial Bureau of Pastures and Forage Crops, Great Britain, has become the Imperial Bureau of Pastures and Field Crops, directed by R. O. Whyte, Penglais, Aberystwyth, Wales, England. The Bureau plans to publish a second abstracting journal in addition to *Herbage Abstracts*. The new journal will cover literature on all cereals, field root crops, pulses, groundnuts, cotton and other fiber crops grown on a field scale, sugar beets, and sugar cane. Research workers are invited to send their publications to the Bureau for review in the new journal.

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Doctor Russell Coleman has been named Director of the Mississippi Agricultural Experiment Station. Doctor Coleman was former

Acting Director following the sudden death of Doctor Clarence Dorman on February 9, 1947. Doctor Frank Welch, Dean of the School of Agriculture of Mississippi State College, has been named Associate Director of the Mississippi Agricultural Experiment Station. Doctor Welch will continue as Dean of the School of Agriculture.

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DOCTOR FRANKLIN L. DAVIS, Louisiana Agricultural Experiment Station, has been appointed Professor of Soils and Soil Chemist at the Alabama Agricultural Experiment Station, Auburn, Ala. Doctor Davis, who was a member of the Alabama staff from 1930-35, will be in charge of liming investigations.

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DOCTOR J. M. SCHOLL has been appointed Associate Agronomist on the staff of the Alabama Agricultural Experiment Station, Auburn, Ala. Doctor Scholl, a native of Wisconsin, received the Ph.D degree at the University of Wisconsin. He will have charge of pasture investigations in the Department of Agronomy and Soils.

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P. B. GIBSON, Assistant Agronomist, and JOHN I. WEAR, Assistant Soil Chemist, Alabama Agricultural Experiment Station, have been granted leaves of absence to continue graduate studies. Mr. Gibson has entered the University of Wisconsin as a General Education Board Fellow, while Mr. Wear has received a Fellowship at Purdue University. Also, W. V. Chandler, Assistant Soil Chemist, and C. M. Wilson, Assistant Professor of Agronomy, Alabama Agricultural Experiment Station, have been granted leaves of absence, effective this fall, to continue graduate training. Mr. Chandler will enter the Ohio State University, while Mr. Wilson will enter North Carolina State College.

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DALE E. WEIBEL has taken a position with Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, and will be stationed at Kansas State College, Manhattan, Kans., in cooperation with the Department of Agronomy. He received his Bachelor of Science degree in 1942 and his Master of Science in 1947 at the University of Nebraska.

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RALPH E. ENGLE, who received his A.B. from Hastings College in 1937 and his Master of Science degree from the University of Nebraska in 1947, has accepted a position with the State College of Agriculture, Department of Agronomy, New Brunswick, N. J. His research and educational work will be on turf and pasture projects.

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ROY C. DAWSON who has been stationed at the Nebraska Agricultural Experiment Station in the employ of the Research Division of the Soil Conservation Service for the past three years received his Ph.D. degree in February, 1947, from the University of Nebraska.

Doctor Dawson returned to Maryland University to continue his work in soil conservation research in cooperation with the Maryland Experiment Station at College Park.

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DOCTOR ROY P. MATELSKI has been appointed Assistant Professor of Agronomy at the University of Nebraska. After his release from the Army in 1946, Doctor Matelski returned to Michigan State College where he completed his advanced degree work in soils. His work at Nebraska will include teaching and research in soil survey and conservation.

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LEON CHESNIN, formerly research assistant at Rutgers University, has recently joined the staff of the University of Nebraska as Assistant Professor of Agronomy. His teaching and research will include soil biochemistry and soil analysis.

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DOCTOR CHARLES E. KELLOGG, Chief of the Division of Soil Survey, U. S. Dept. of Agriculture, returned July 24 from a three months' visit in Europe and Africa. He attended the Mediterranean Conference of Pedology in southern France and Algeria, took part in a small conference held in Paris to plan for reorganization of the International Society of Soil Science, and visited the Rothamsted Experimental Station and the University College of North Wales. As the guest of IN&AC (Institut National pour l'Étude Agronomique du Congo Belge) he travelled for five weeks in the Belgian Congo, visiting experimental stations and studying soils and agriculture in the field.

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PROFESSOR CHARLES BURGESS WILLIAMS, first Dean of the North Carolina State College of Agriculture and long active in the affairs of the American Society of Agronomy, died at his home in Raleigh on June 25th at the age of 76.

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MAILING of Volume 11 of the PROCEEDINGS of the Soil Science Society containing the papers presented at the Omaha meeting is expected to get under way within a short time. The volume will run considerably larger than Volume 10.

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DOCTOR G. S. FRAPS, after 44 years with the Texas Agricultural Experiment Station, retired on July 31, 1947. When placed on limited service on August 31, 1945, he was Chief of the Division of Chemistry and State Chemist of Texas. He is the author of two books and author or co-author of over 400 bulletins and scientific publications. His work deals with the composition, fertility and conservation of plant food in Texas soils, the nature and use of commercial fertilizers, analyses of commercial fertilizers and feeding stuffs, composition, feeding values and utilization of Texas feeds, definitions of fertilizers and commercial feeds, vitamins, energy values of foods and feeds, and other topics.

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Complementary Genes for Leaf Rust Resistance and the Inheritance of Stem Rust Reaction and Awnedness in a Spring Wheat Cross[1]

S. P. SWENSON, W. F. BUCHHOLTZ, AND J. E. GRAFIUS[2]

THIS paper is concerned primarily with the occurrence of plants and lines resistant to leaf rust, *Puccinia rubigo-vera tritici* (Erikss. and Henn.) Carl., in the progeny of a cross between two susceptible varieties of spring wheat, *Triticum aestivum* L., Thatcher (C.I. No. 10003) and Triunfo (F.P.I. No. 104138). Segregation also was observed for reaction to stem rust, *Puccinia graminis tritici* Erikss. and Henn., and for awnedness so that data on these two characters and on the interrelations of all three characters are presented and interpreted.

REVIEW OF LITERATURE

Only a limited amount of research has been conducted on the genetics of resistance to leaf rust. The first published study was a rather comprehensive one by Mains, *et al.* (5)[3] on the inheritance of the resistance of the Kanred and Malakoff varieties to a mixture of physiologic races in the mature plant stage in the field, and of the resistance of several varieties to specific races in the seedling stage in the greenhouse. They concluded that several genes were involved. Wismer (9) obtained highly resistant F_4 lines from a cross between Oro, which is highly susceptible, and Tenmarq, which is moderately susceptible, and he concluded that each parent carried genes for resistance. A simpler type of inheritance has been reported in crosses involving the resistance of H-44 by Hayes, *et al.* (2) who postulated one or two gene pairs to account for their results. In a study by Wells and Swenson (8), one main gene pair appeared to be involved in a cross between an H-44 derivative and a very susceptible selection of Hard Federation-Dicklow. Later studies by Swenson (unpublished data) have demonstrated that the resistance of Hope is differentiated from the reaction of Federation by one gene pair.

The authors are aware of no report on a comprehensive study of the field reaction to stem rust of Thatcher in crosses with susceptible varieties. Neatby (6) published limited data from a Thatcher×Garnet cross which indicated that field resistance in Thatcher is recessive and determined by two or more genes. Further suggestions on the probable genetic behavior of Thatcher, when crossed with a susceptible variety, are available from studies of related material. Hayes, *et al.* (3) studied a cross between Marquillo, a sister of Marquis-Iumillo Selection II-15-44 which was one of the parents of Thatcher, and Marquis-Kanred, a selection of which was the other parent. They concluded that at least two genes determined the resistance of Marquillo, and that Marquis-Kanred carried one gene for immunity from 11 races of stem rust. These results and those of Neatby and Goulden

[1]Journal Paper No. 206, South Dakota Agricultural Experiment Station, Brookings, S. D. Received for publication April 17, 1947.

[2]Formerly Associate Agronomist, formerly Plant Pathologist, and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 749.

(7) from a Marquillo×Marquis-Kanred cross indicate that three or more genes for resistance are present in Thatcher. However, Neatby and Goulden, in the same paper, reported the results of a cross between Double Cross (probably Thatcher) and H-44 in which three genes, the H-44 gene and two complementary recessive genes in Thatcher, appeared to be segregating. Hayes, *et al.* (2) also studied a cross between H-44 and Thatcher but made no attempt to determine the number of genes contributed by Thatcher. The data of both Neatby and Hayes, *et al.*, demonstrated that different genes for resistance are present in H-44 and Thatcher.

The literature on the inheritance of awnedness has been reviewed in detail by Clark (1).

MATERIALS AND METHODS

FIELD STUDIES

The cross Thatcher×Triunfo was made in 1937 for the purpose of combining the high test weight and post-heading tolerance to high temperatures of Triunfo with the stem rust resistance, yield, and high quality of Thatcher. Thatcher is susceptible to leaf rust, resistant to stem rust, and awnleted, while Triunfo is susceptible to leaf rust, susceptible to stem rust, and awned.

Segregation for leaf rust reaction was overlooked in an F_2 population grown in 1938, but 413 F_2 plants were selected for resistance to stem rust and high weight per 1,000 kernels. In addition, a random population of 180 F_2 plants was saved for an F_3 genetic study of stem rust reaction and weight per 1,000 kernels. Two replications of the F_3 progenies of all of the 593 selections, planted in 6-foot rows with 25 seeds per row, were grown in 1939. One row of each parent was grown with every 20 F_3 lines. In addition, a population of 958 F_2 plants was included in the study.

In order to check and verify the results obtained in 1939, a random population of 88 F_3 lines from F_2 plants grown in 1939 and three rows of each parent were studied in 1940.

The epiphytotics of leaf rust and stem rust occurred naturally, but artificial inoculations with stem rust in susceptible borders also were made in 1939.

Six classes, based on the percentage of infection and the type of pustule, were used to classify the reactions of individual plants to leaf rust as follows: resistant (R), resistant- (R-), moderately resistant (MR), moderately susceptible (MS), susceptible (S), and very susceptible (VS). The corresponding percentages of infection were approximately as follows: R (5% or less), R- (6 to 10%), MR (11 to 20%), MS (21 to 30%), S (31 to 50%), and VS (50% or more). The types of reaction described by Mains and Jackson (4) were used as a basis for attempting to recognize types of pustules and for distinguishing between plants classified as resistant and those classified as susceptible. Recognition of the type of pustule was particularly useful in determining whether certain plants should be classified as MR or MS. Consequently, some plants with slightly more than 20% infection but with type 1 or 2 pustules predominating were classified as MR, while others with less than 20% infection but with type 3 or 4 pustules predominating were classified as MS.

Stem rust reactions also were classified into six classes, primarily on the basis of percentages of infection because types of reaction could not be clearly recognized. The descriptive symbols from R to VS were used in preference to the percentages, as in the case of leaf rust.

In classifying for awns, three classes of plants were recovered and classified as follows: awnleted like Thatcher, awned like Triunfo, and intermediate like the F_1.

GREENHOUSE STUDIES

Seedlings tested in the greenhouse for leaf rust reaction were grown in pots and inoculated by the usual method of applying spores with a scalpel to the leaf blade and incubating in a moist chamber.

EXPERIMENTAL RESULTS

REACTION TO LEAF RUST

Field studies of mature plant reaction.—The epiphytotic of leaf rust in the 1939 nursery was a severe one, as indicated by the fact that all

plants of Thatcher were classified as susceptible and only two plants of Triunfo were classified as resistant, both of them R- and probable escapes. The pustules on Thatcher appeared to be more numerous but smaller than those on Triunfo, the Thatcher pustules approaching a type 3 and the Triunfo pustules a type 4. Because of the smaller pustules, all of the Thatcher plants were classified as moderately susceptible (MS) or susceptible (S), while Triufno plants, because of their larger pustules, were frequently classified as very susceptible (VS).

The segregating material exhibited all degrees of infection from highly resistant to very susceptible. A strong correlation was observed between type of reaction and percentage of infection, and usually the distinction between plants showing a resistant reaction and plants showing a susceptible reaction could be made with considerable confidence. However, some of the material was difficult to classify because of variations in degree of maturity and the occurrence of plants and lines exhibiting other leaf diseases, or because of physiological deterioration of the tissues. On plants thus affected, leaf rust often was arrested in its development at an early stage. Frequently, though, at least one green leaf could be found on such plants so a satisfactory reading could be made; otherwise, the plant was discarded.

In 1940, the epiphytotic which developed in the earlier F_4 material was almost as severe and uniform as the one in 1939 on the F_2 plants and F_3 lines. The 1940 F_3 lines, planted 3 weeks later than the F_4's, did not encounter such favorable conditions for infection. Previous to heading, a large number of the F_3 plants became infected with bacterial leaf blight and as the plants were heading, hot dry weather arrived. Consequently, conditions were not favorable for infection and many susceptible plants probably escaped, as indicated by the presence of escapes in both parents. Severe leaf degeneration also occurred on many of the plants, making it difficult or impossible to obtain reliable leaf rust readings.

A summary of the data on the mode of inheritance of reaction to leaf rust is presented in Table 1. As pointed out previously, only the F_2's and the randomly selected F_3 lines were classified strictly on an individual plant basis. Because of overlapping between the three classes within the resistant and susceptible groups, it was impossible to identify all of the specific F_2 genotypes or groups of similar F_2 genotypes from which the F_3 lines were derived. Consequently, there appeared to be little advantage in indicating more than two classes for individual plant reactions, resistant (R) to include R, R-, and MR, and susceptible (S) to include MS, S, and VS. However, the finer divisions facilitated the classification of F_3 lines into the three groups indicated in the table—resistant, segregating (R-S), and susceptible. For example, several lines contained a preponderance of susceptible plants with only a few plants classified as R- or R. If most of the latter plants were R-, they and occasional R plants were assumed to be escapes and the lines were classified as being homozygous susceptible. In other instances, several R- plants were found in lines which were otherwise all R and in which there had been con-

siderable leaf deterioration. Such R- plants were assumed to be susceptible plants which had escaped severe infection and the lines were classified as segregating. Unfortunately, no F_1 plants were grown in either 1939 or 1940 to provide observation of the reaction of the F_1 heterozygote. However, examination of leaf rust readings taken in 1938 revealed that the percentage of infection of F_1 plants of Thatcher $\times$Triunfo was estimated at 5% in a severe epiphytotic. This indicates that F_1 plants probably would have been classified as R- or resistant.

TABLE 1.—*Reaction to leaf rust of parents, F_2 plants, and F_3 lines of the cross Thatcher and Triunfo in 1939 and 1940.*

Parent or generation	Number of plants, rows, or lines showing indicated reaction				X^2 for goodness of fit to a 1:8:7 ratio	X^2 for goodness of fit to a 9:7 ratio
	R	R-S	S	Total		
1939 Data						
Thatcher, plants	—	—	25	25	—	—
Triunfo, plants	—	—	22	22	—	—
F_2, plants	558	—	400	958	—	1.551
Thatcher, rows	—	—	9	9	—	—
Triunfo, rows	—	1	8	9	—	—
F_3, lines, random population	12	98	70	180	1.733	1.728
F_3, lines, from F_2 plants selected for stem rust resistance and plump kernels	30	266	117	413	Very large**	Very large**
1940 Data						
Thatcher, rows	—	1	2	3	—	—
Triunfo, rows	—	2	1	3	—	—
F_3, lines, random population	12	48	28	88	10.910**	5.091*

*Significant.
**Highly significant.

The most logical interpretation of the results is that complementary genes are involved. The F_2 ratio in 1939 of 558 resistant (R, R-, or MR) to 400 susceptible (MS, S, or VS) plants agreed with a 9:7 ratio very well, suggesting that each parent contributed one of two complementary genes for resistance.[4] The 180 randomly selected F_3 lines grown in 1939 also segregated in accordance with this hypothesis, as shown by the low values of chi square for goodness of fit to 1:8:7 and 9:7 ratios. The 88 F_3 lines grown in 1940, on the other hand, did not result in as good a fit because of an excess of lines in the first two classes and a deficiency in the last class. Because of the difficulties encountered in classification, these discrepancies were attributed to

[4]Additional F_2 data were obtained in 1944 by the junior author on 247 plants which segregated 145 resistant to 102 susceptible, an excellent fit (X^2=.612) to a 9:7 ratio.

escapes which would permit occasional segregating lines to be classified as breeding true for resistance and occasional susceptible lines to be classified as segregating. Evidence on this point is available from 17 of the lines which were retested in 1941 during an exceptionally heavy epiphytotic of leaf rust. Of three lines classified as homozygous resistant in 1940, one was classified as segregating in 1941. Eleven of the lines were classified as segregating in 1940 and two of these were susceptible in 1941. Three lines which were susceptible in 1940 also were susceptible in 1941.

The 413 F_3 lines grown in 1939 from F_2 plants selected in 1938 for stem rust resistance and plump kernels exhibited very poor agreement with the calculated ratios because of excesses in the first two classes and a marked deficiency in the last class. The discrepancies may be due in part to less careful classification of these lines. However, a more plausible explanation is that when the F_2 plants were selected for plumpness of kernel, there also was unconscious selection for resistance to leaf rust. The season of 1938 was characterized by a very heavy epiphytotic of leaf rust which markedly reduced the kernel weight of susceptible varieties in the yield trials. Therefore, it is reasonable to suppose that plants resistant to leaf rust would have produced heavier kernels than susceptible plants.

Additional support for the postulation of two complementary genes is available from the ratios of resistant to susceptible plants in the segregating lines. Theoretically, one half of the segregating lines should be segregating 3R:1S and the other half should segregate 9R:7S. An attempt was made to separate the segregating lines on this basis, but the number of plants per line was too small to permit an accurate separation. However, the lines fell into two approximately equal groups, the 9:7 group being slightly larger than the 3:1 group.

Although the erratic behavior of some of the lines appears to be attributable to variations in degree of maturity and to leaf deterioration, the possibility of one or more modifying genes cannot be ignored. The data on the 413 F_3 lines grown in 1939 from selected F_2 plants and the 88 randomly selected F_3 lines in 1940 are in reasonably good agreement with a 7:38:19 ratio. This ratio would be obtained if two genes, noncomplementary to each other, are contributed by one of the parents and if both of these genes are complementary, singly or in combination, with one gene contributed by the other parent. Even the randomly selected F_3 lines in 1939 can be fairly logically reassigned to give a ratio of 19:97:64, an excellent fit to the 7:38:19 ratio. This hypothesis also would aid in explaining the occurrence of F_3 lines within which the ratios agree with neither a 9:7 or 3:1 ratio very well. The F_2 data, however, are not in good agreement with this hypothesis. Furthermore, F_4 progeny tests indicated that some of the F_3 plants from lines classified as resistant were actually heterozygous and had escaped severe infection in 1939. The two-gene hypothesis, therefore, is regarded as more tenable than the alternative three-gene hypothesis.

A check on the accuracy of the 1939 classifications is provided by the reactions of progenies grown in 1940. In Table 2 are shown the reactions of the 88 randomly selected F_3 lines in relation to the re-

actions of the F_2 plants from which they were derived. The results reveal that several susceptible plants escaped severe infection in 1939 and also indicate that escapes were occurring in 1940, as has been pointed out previouly in this discussion. The relationships between F_4 progenies and their parent F_3 plants, as shown in Table 3, also indicate the occurrence of escapes and errors in classification in 1939. The 69 progenies from R lines represent plants from 24 different F_3 lines, half of which contained heterozygous plants as determined by the 1940 classification. Of the 496 R plants saved from segregating lines, 26 gave progenies which were classified as all susceptible.

TABLE 2.—*Reaction to leaf rust in 1940 of F_3 progenies of 88 randomly selected F_2 plants classified as resistant or susceptible in 1939.*

Reaction of F_2 plant from which F_3 progenies were grown	Number of F_3 lines showing indicated reaction			
	R	R-S	S	Total
R	12	46	9	67
S	0	2	19	21
Total	12	48	28	88

In attempting to explain the discrepancies which have been noted, the presence of several physiologic races should not be overlooked as a possible disturbing factor. No collections of leaf rust were made in 1939 but greenhouse studies of collections made in 1940 revealed that at least two races, 6 and 20, were prevalent in the nursery. Additional races also were found to be present.[5]

The complementary effect observed in the progenies of the two susceptible parents might be the result of a situation whereby the gene contributed by Thatcher controls resistance to one race or group of races, and the Triunfo gene governs resistance to another race or group of races. Plants or progenies carrying both genes then would exhibit resistance to all races influenced in their effects by the two genes. Preliminary studies on this point were made in the greenhouse and are reported in a succeeding section.

Breeding behavior of resistant selections in later generations.—In

TABLE 3.—*Reaction to leaf rust in 1940 of F_4 progenies of F_3 plants selected from F_3 lines classified as homozygous resistant or as segregating in 1939.*

Reaction of F_3 line from which resistant plants were selected for F_4 progeny test	Number of F_4 lines from selected F_3 plants showing indicated reaction			
	R	R-S	S	Total
R	43	26	0	69
R-S	164	306	26	496
Total	207	332	26	565

[5]Collections by M. N. Levine, identified by C. O. Johnston.

Table 4 are shown the leaf rust reactions of three pure lines, selected in F_6 in 1942, in comparison with the parents and with Pilot and Rival, two resistant commercial varieties, for the years 1943, 1944, 1945, and 1946. The resistance of the Thatcher×Triunfo derivatives appears to be more effective than the resistance of Pilot and Rival which was derived from Hope.

TABLE 4.—*Percentage infection with leaf rust in 1943, 1944, 1945, and 1946 of three Thatcher×Triunfo selections made from F_6 lines in 1942, the two parents, and two resistant commercial varieties, Pilot and Rival.*

Variety or selection	Percentage leaf rust			
	1943	1944	1945	1946
Pilot	5	10	40	20
Rival	5	10	15	10
Thatcher	80	60	80	40
Triunfo	80	60	10	20
Thatcher×Triunfo 339	Trace	Trace	Trace	Trace
Thatcher×Triunfo 630	Trace	5	5	3
Thatcher×Triunfo 343	Trace	Trace	Trace	3

It is interesting to note that very little leaf rust occurred on Triunfo in 1945 and 1946. A similar observation was made by the senior author in 1942 at Pullman, Wash., where leaf rust did not appear on Triunfo as early or as readily as it did on Thatcher. However, when pustules did appear, they were distinctly of the large susceptible type. It is entirely possible that low temperature or some other climatic condition may be responsible for this reaction.

Greenhouse studies.—During the winter of 1940–41, collections of leaf rust from Thatcher and Triunfo in the 1940 field nursery were tested for race content in the greenhouse on the standard set of eight differential wheat varieties.[6] Races 6 and 20 were isolated from the Thatcher collections and race 20 from Triunfo collections. As previously mentioned, collections made by Dr. M. N. Levine included additional races.

After the identity of races 6 and 20 had been established, the two parents and 36 F_3 lines, grown from remnant seed remaining from the 1940 F_3 lines, were tested for seedling reaction to the two races. Of the 36 F_3 lines, two had been classified in the field as breeding true for resistance, 23 as segregating, and 11 as susceptible. All of the 36 lines, as well as both parents, proved to be completely susceptible to both races in the seedling stages. Occasional plants appeared to be immune, but they exhibited no flecks or necrosis to indicate that infection had occurred; furthermore, repeated tests indicated they had escaped infection. Consequently, they were judged to be escaped rather than immune plants.

As a possible explanation of the field results, mature plant resistance was postulated. To obtain preliminary information on this point, the flag or next lower leaves of plants of two resistant, three

[6]Kindly supplied by C. O. Johnston.

segregating, and three susceptible F_3 lines, as determined in the field, were tested for their mature plant reactions to races 6 and 20. All of these lines appeared to be susceptible to both races. A few plants exhibited no rust, but repeated tests indicated that they had escaped infection. Consequently, the greenhouse results fail to confirm or explain the results obtained in the field.

It is apparent that further work is necessary to account for the field results with respect to races of rust, the nature of the resistance observed in the resistant progenies, and the relation of environmental factors such as temperature and humidity to resistance.

REACTION TO STEM RUST

The stem rust epiphytotics were only moderately severe in both 1939 and 1940, the one in 1939 being more uniform throughout the nursery than the one in 1940. Percentage readings on individual plants within the parental rows in 1939 ranged from 2 to 10 with a mode of 5 for Thatcher, and from 20 to 70 with a mode of 40 for Triunfo. No percentage readings were made in 1940, but it was estimated that, except for occasional escaped plants, the epiphytotic was slightly more severe than the one in 1939.

The segregating material exhibited a wide range of reaction, classifiable only on the basis of percentage of infection. In the analysis of the data, the descriptive symbols (R to VS) were used instead of percentages to describe the classes. Furthermore, the R- plants were grouped with R plants and VS plants were grouped with S plants.

A summary of the data on reactions of the parents and F_3 lines is given in Table 5, arranged in increasing order of resistance because of the dominance of susceptibility. Data also were obtained in 1939 on the individual plant reactions of 796 F_2 plants, but, as will be shown later, they were not considered sufficiently reliable to be included in the table.

At least two or three recessive genes appear to be involved in the inheritance of the reaction of Thatcher to stem rust. In 1939, 10 out of 180 F_3 lines were classified as MR-R, but these lines contained a preponderance of MR plants, whereas the six Thatcher rows classified as MR-R contained only occasional plants classified as MR. The one F_3 line classified as R in 1940 appeared to be as resistant as Thatcher, but it was not subjected to further progeny tests. If this one line is considered as the only one possessing the full resistance of Thatcher, as many as four gene pairs are indicated. These results are in general agreement with those of Hayes, *et al.* (3), Neatby (6), and Neatby and Goulden (7).

A check on the accuracy of readings of individual plant reactions in 1939 is provided by the reactions of F_3 progenies grown in 1940 from F_2 plants classified in 1939. The data are presented in Table 6. It is apparent that under the conditions of this study, individual plant reactions were not sufficiently reliable to justify a genetic analysis of F_2 data.

AWNEDNESS

The data on the inheritance of awnedness are presented in Table 7. The results from the random populations of F_2 plants and F_3 lines

provide conclusive evidence that one gene pair is involved. No evidence of transgressive segregation of awn types was observed. The excessive number of awned plants and the higher X^2 value for the selected F_3 lines is very likely attributable to an unconcious selection of awned types when the F_2 plants were selected for plumpness of kernel.

TABLE 5.—*Reaction to stem rust of parents and F_3 lines of the cross Thatcher×Triunfo in 1939 and 1940.*

Parent or generation	Number of rows or lines showing indicated reaction							Total
	S	S-MS	S-MR	S-R	MS-R	MR-R	R	
				1939 Data				
Thatcher, rows	—	—	—	—	—	6	3	9
Triunfo, rows	4	5	—	—	—	—	—	9
F_3, lines, random population	17	32	40	66	15	10	—	180
				1940 Data				
Thatcher, rows	—	—	—	—	—	2	1	3
Triunfo, rows	1	2	—	—	—	—	—	3
F_3, lines, random population	21	12	16	31	6	1	1	88

TABLE 6.—*Reaction to stem rust in 1940 of F_3 progenies of 88 randomly selected F_2 plants classified into four classes in 1939.*

Reaction of F_2 plant from which F_3 progenies were grown	Number of F_3 lines showing indicated reaction							Total
	S	S-MS	S-MR	S-R	MS-R	MR-R	R	
R	—	—	—	1	2	1	1	5
MR	3	2	3	10	3	—	—	21
MS	5	4	3	12	1	—	—	25
S	13	6	10	8	—	—	—	37
Total	21	12	16	31	6	1	1	88

INTERRELATIONS OF CHARACTERS

A summary of X^2 values from tests for independence of the three characters is presented in Table 8. In making these tests, the stem rust classes shown in Table 4 were grouped into three larger classes with S and S-MS in the first group; S-MR, S-R, and MS-R in the second group; and MR-R and R in the third group. Leaf rust reactions and awn types were left in three classes so that all three tests for independence were made from 3×3 tables.

The three characters can be assumed to be independently inherited since none of the X_2 values is significant.

TABLE 7.—*Segregation for awn type in F_2 and F_3 of the cross Thatcher×Triunfo in 1939 and 1940.*

Generation and year	Number of plants or lines showing indicated awn types			Total	X^2 for goodness of fit to a 1:2:1 ratio
	Awnleted	Heterozygous or segregating	Awned		
F_2, plants, 1939	209	401	186	796	1.375
F_3, lines, random populations in 1939 and 1940	61	136	71	268	0.806
F_3, lines, from F_2 plants selected for stem rust resistance and plump kernels	97	190	126	413	6.709*

*Significant.

SUMMARY

Plants and lines which were highly resistant to leaf rust occurred in the progeny of a cross between two susceptible varieties, Thatcher and Triunfo. The segregations obtained in F_2 and F_3 were fairly satisfactorily explained by postulating two complementary dominant genes, one from each parent. Because there was some indication that one or more modifying genes might be present, an alternative hypothesis involving three gene pairs also was suggested. Under this hypothesis, two genes, noncomplementary to each other, are contributed by one parent, and these two genes are complementary, either singly or in combination, with one gene contributed by the other parent.

Preliminary studies in the greenhouse on mature plant reactions indicated that the complementary effect observed in the field was not the result of a situation whereby the gene contributed by Thatcher conditions resistance to one race or group of races, and the Triunfo gene governs resistance to another race or group of races.

Greenhouse studies of seedling reactions revealed that the resistance observed in the field is a mature plant reaction. Seedlings from resistant, segregating, and susceptible lines all proved to be completely susceptible.

TABLE 8.—*Summary of X^2 tests for independence of reaction to leaf rust, reaction to stem rust, and awnedness.*

Characters	Degrees of freedom	X^2
Leaf rust and stem rust	4	5.029
Leaf rust and awnedness	4	2.892
Stem rust and awnedness	4	7.757

The subsequent breeding behavior of resistant selections indicates that the leaf rust resistance of Thatcher×Triunfo derivatives is more effective than that observed in certain Hope derivatives.

At least two or three recessive genes for resistance to stem rust were involved in differentiating between the resistant reaction of Thatcher and the susceptibility of Triunfo.

Awnleting in Thatcher and awnedness in Triunfo were found to be differentiated by one gene pair

X^2 tests for independence of the three characters, leaf rust reaction, stem rust reaction, and awnedness, revealed no indication of linkage.

LITERATURE CITED

1. CLARK, J. ALLEN. Improvement in wheat. U.S.D.A. Yearbook of Agriculture, 1936:207–302. 1936.
2. HAYES, H. K., AUSEMUS, E. R., STAKMAN, E. C., and BAMBERG, R. H. Correlated inheritance of reaction to stem rust, leaf rust, and black chaff in spring-wheat crosses. Jour. Agr. Res., 48:59–66. 1934.
3. ————, STAKMAN, E. C., and AAMODT, O. S. Inheritance in wheat of resistance to black stem rust. Phytopath., 15:371–388. 1925.
4. MAINS, E. B., and JACKSON, H. S. Physiologic specialization in the leaf rust of wheat, *Puccinia triticina* Erikss. Phytopath., 16:89–120. 1926.
5. ————, LEIGHTY, C. E., and JOHNSTON, C. O. Inheritance of resistance to leaf rust, *Puccinia triticina* Erikss., in crosses of common wheat, *Triticum vulgare* Vill. Jour. Agr. Res., 32:931–972. 1926.
6. NEATBY, K. W. Factor relations in wheat for resistance to groups of physiologic forms of *Puccinia graminis tritici*. Sci. Agr., 12:130–154. 1931.
7. ————, and GOULDEN, C. H. II. The inheritance of resistance to *Puccinia graminis tritici* in crosses between varieties of *Triticum vulgare*. Sci. Agr., 10:389–404. 1930.
8. WELLS, D. G., and SWENSON, S. P. Inheritance and interaction of genes governing reaction to stem rust, leaf rust, and powdery mildew in a spring wheat cross. (Abstract.) Jour. Amer. Soc. Agron., 36:991–992. 1944.
9. WISMER, C. A. Inheritance of resistance to bunt and leaf rust in the wheat cross, Oro×Tenmarq. Phytopath., 24:762–799. 1934.

Productiveness of Bromegrass Strains from Different Regions when Grown in Pure Stands and in Mixture with Alfalfa in Michigan[1]

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STUDIES of smooth bromegrass, *Bromus inermis* Leyss, made of individual plants have shown marked differences in growth characters. Nursery row plantings likewise have shown these differences to exist among strains from different sources. Investigations by Newell and Keim[3] in Nebraska indicate that some strains are more adapted to certain areas than others and that production is influenced in part by choice of strain grown. Strains (planted in pure stands) were grouped as northern, or late, and southern, or early. Southern strains were more vigorous, made most of their growth earlier, and were more productive than northern strains.

In order to compare the yielding ability of bromegrass strains from different seed sources under Michigan conditions, seedings were made in mid-August of 1940 and 1942 in pure stands and in mixtures with Hardigan alfalfa.

MATERIAL AND METHOD

Seed was secured from several of the bromegrass-producing states, from Canada, and from Russia. Information regarding these strains is given in Table 1. Some of the strains occur only in the first test, some are included in only the second test, while several are in both trials.

Plots were 15×29 feet from which a 6-foot plot was harvested 29 feet long. Strains were randomized and planted in duplicate. Seed was broadcast by hand on a Brookston loam soil which had previously been fertilized with 400 pounds per acre of an 0–20–20 commercial fertilizer. The field was cultipacked immediately after seeding. Heavy rates of seeding were used for both the bromegrass (10 pounds per acre) and the alfalfa (12 pounds per acre). The 1942 seedings were made in the same manner as those in 1940 except rates of seeding of bromegrasses were adjusted for differences in purity and germination. Good stands were secured for all plots in both trials.

Analyses to determine the percentage of bromegrass and percentage of bromegrass leaves and tillers were made just previous to harvest. Moisture determinations were made in an oven dryer for each plot. Data are presented only for one series each year for the 1940 seedings because of serious damage to some plots caused by water and ice. Yield data for the 1942 seedings are the average of duplicate plots.

RESULTS

HAY YIELDS

All of the bromgrass strains were productive the first year after seeding. From the 1940 seedings the average yield of all bromegrass

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[3]NEWELL, L. C., and KEIM, F. D. Field performance of bromegrass strains from different regional seed sources. Jour. Amer. Soc. Agron., 35:420–434. 1943.

strains when grown alone was 100, 75, and 58% for the first, second, and the third year, respectively. From the 1942 seedings the average yield of all bromegrass strains when grown alone was 100, 73, and 36% for the first, second, and third year, respectively.

TABLE 1.—*Seed source and identification of bromegrass strains grown.*

Michigan No.	Seed source	Identification of strain
1	Nebraska	Nebraska 90
2	North Dakota	D 607
3	North Dakota	D 22 (Sask. 38)
4	Montana	F.C. 30305
5	Saskatchewan	Sask. S-23-7-1-2-3
6	Michigan	Michigan certified
7	North Dakota	Bulk seed Northern Great Plains Field Sta.
8	Nebraska	Nebr. 10–3488
9	Ohio	Eichling strain
10	Iowa	Marshall Farm
11	North Dakota	F. C. 22706
12	Montana	Commercial crop
13	Kansas	Achenbach strain
14	North Dakota	Commercial crop
15	U.S.D.A., Washington, D. C.	Parkland
16	North Dakota	D 608
17	Utah	B 11
18	Utah	B 12
19	Commercial trade	Canadian certified
20	U.S.D.A.	Lenningrad Russia
21	U.S.D.A.	Lenningrad Russia
23	U.S.D.A.	Lenningrad Russia
25	North Dakota	965–185

From first cuttings of the 1940 seedings the combined yield of alfalfa and grass as an average of all strains was 100, 77, and 90% for the first, second, and third year, respectively. From first cuttings of the 1942 seedings the combined yield of alfalfa and grass as an average of all strains was 100, 110, and 102% for the first, second, and third year, respectively.

No strain when grown alone made enough growth to justify a second cutting. When grown alone, the average yields of the lowest producing strain from the 1940 and 1942 seedings were 49 and 54% that of the highest yielding strain, respectively. When grown in mixture with alfalfa, the lowest yielding strain based on combined yield of alfalfa and bromegrass was 78 and 69% that of the highest yielding strain for the 1940 and 1942 seedings, respectively. Thus, differences in yielding ability of strains were less pronounced when the bromegrass was grown in mixture with alfalfa. Yields of the different strains when grown in pure stands are given in Table 2 in tons per acre and in percentage of the Kansas strain. It will be noted that yields of Kansas (Achenbach) and Nebraska 10–3488 were practically identical and considerably higher than the other strains.

TABLE 2.—*Yields of bromegrass strains when grown in pure stands at East Lansing, Mich., 3-year averages.*

Strain	Strain No.	1940 seedlings		1942 seedings		Average of both tests	
		Tons per acre	% of Kansas	Tons per acre	% of Kansas	Tons per acre	% of Kansas
Nebraska 90	1	1.50	76	—	—	—	—
North Dakota D607	2	1.13	57	—	—	—	—
North Dakota D22	3	1.07	54	—	—	—	—
Montana	4	1.24	63	—	—	—	—
Saskatchewan	5	1.02	52	—	—	—	—
Michigan	6	1.39	71	1.57	87	1.48	78
North Dakota Bulk	7	1.37	69	1.59	88	1.48	78
Nebraska 10–3488	8	2.09	106	1.77	98	1.93	102
Ohio	9	1.41	72	1.57	87	1.49	79
Iowa	10	1.30	66	1.58	87	1.44	76
North Dakota	11	1.16	59	1.37	76	1.27	67
Montana	12	1.45	74	—	—	—	—
Kansas Achenbach	13	1.97	100	1.81	100	1.89	100
North Dakota	14	1.46	74	—	—	—	—
Parkland	15	1.26	64	1.36	75	1.31	69
North Dakota D608	16	1.45	74	1.64	91	1.55	82
Utah B-11	17	—	—	1.74	96	—	—
Utah B-12	18	—	—	1.82	101	—	—
Canadian certified	19	—	—	1.30	72	—	—
Russian	20	—	—	1.09	60	—	—
Russian	21	—	—	1.38	76	—	—
Russian	23	—	—	0.98	54	—	—
North Dakota	25	—	—	1.45	80	—	—

Yields of the strains when grown in mixture with alfalfa are given in Table 3 in tons per acre and in percentage of the Kansas strain. These data include only the first cuttings and can be compared with data in Table 2. Differences in yield when grown in mixture with alfalfa were smaller and several strains which were very low when grown in pure stand produced combined yields with alfalfa more comparable to several other strains. Yields of the Kansas and Nebraska strains were highest, but a few other strains were only slightly lower. In the 1942 trials where pure stands of alfalfa were also harvested, all strains in mixture with alfalfa yielded more in combination with alfalfa than alfalfa grown in pure stands.

Yields from second cuttings of all plots containing alfalfa taken the second and third years are given in Table 4. Yields were considerably lower from the second than from the first cuttings. All plots contained a higher percentage of alfalfa in the second cuttings and differences between strains were much smaller. The average yields per season of bromegrass and alfalfa when grown in mixture are given in Table 5. Yields per season were highest from the Kansas strain and lowest from Russian strains 20 and 21 and from pure alfalfa.

TABLE 3.—*Combined yields of bromegrass strains with alfalfa when grown in mixtures at East Lansing, Mich., 3-year average from first cuttings.*

Strain	Strain No.	1940 seedings			1942 seedings			Average of both tests	
		Tons per acre	% of Kansas	% bromegrass in mixture	Tons per acre	% of Kansas	% bromegrass in mixture	Tons per acre	% of Kansas
Nebraska 90.	1	2.35	86	—	—	—	—	—	—
North Dakota D607......	2	2.11	78	—	—	—	—	—	—
North Dakota D22.......	3	2.22	82	—	—	—	—	—	—
Montana....	4	2.19	80	—	—	—	—	—	—
Saskatchewan	5	2.11	78	—	—	—	—	—	—
Michigan....	6	2.17	80	51.2	2.18	85	70.8	2.18	82
North Dakota bulk......	7	2.33	86	42.8	2.43	95	74.5	2.38	90
Nebraska 10–3488	8	2.47	91	54.5	2.53	98	70.3	2.50	94
Ohio........	9	2.30	84	55.7	2.25	87	73.5	2.28	86
Iowa........	10	2.32	85	—	2.16	84	70.2	2.24	84
North Dakota	11	2.36	87	—	2.04	79	73.0	2.20	83
Montana....	12	2.20	81	—	—	—	—	—	—
Kansas Achenbach..	13	2.72	100	—	2.57	100	70.2	2.65	100
North Dakota	14	2.39	88	—	—	—	—	—	—
Parkland....	15	2.24	82	28.7	2.04	79	56.6	2.14	81
North Dakota D608......	16	2.31	85	—	2.27	88	69.5	2.29	86
Utah B-11...	17	—	—	—	2.17	84	74.5	—	—
Utah B-12...	18	—	—	—	2.38	93	66.6	—	—
Canadian certified......	19	—	—	—	2.17	84	74.5	—	—
Russia.......	20	—	—	—	1.77	69	19.6	—	—
Russia.......	21	—	—	—	1.87	73	43.3	—	—
Russia.......	23	—	—	—	2.12	82	56.7	—	—
North Dakota	25	—	—	—	2.15	84	62.3	—	—
Alfalfa, pure stand......	—	—	—	—	1.72	67	0	—	—

DRY MATTER

The percentage of dry matter in the bromegrass when grown alone and in mixture with alfalfa varied with the strain, the season, and the cutting. From the 1940 seedings the percentage of dry matter in all strains from first cuttings when grown alone ranged from 31.2 to 40.8 in 1941. In 1942 the range was 31.1 to 41.6 and in 1943 it was 31.3 to 37.2. From the 1942 seedings this range was 31.0 to 37.2 in 1943, 29.8 to 36.8 in 1944, and 29.9 to 35.3 in 1945. The percentage of

TABLE 4.—*Combined yields of bromegrass strains with alfalfa in mixture at East Lansing, Mich., 2-year average of second cuttings taken in the second and third years.*

Strain	Strain No.	1940 seedings			1942 seedings			Average of both tests	
		Tons per acre	% of Kansas	% bromegrass in mixture	Tons per acre	% of Kansas	% bromegrass in mixture	Tons per acre	% of Kansas
Nebraska 90	1	1.30	86	—	—	—	—	—	—
North Dakota D607	2	1.40	93	—	—	—	—	—	—
North Dakota D22	3	1.51	101	—	—	—	—	—	—
Montana	4	1.40	93	—	—	—	—	—	—
Saskatchewan	5	1.44	96	—	—	—	—	—	—
Michigan	6	1.35	90	26.5	0.98	111	31.1	1.17	98
North Dakota bulk	7	1.37	91	36.1	0.88	100	25.9	1.13	95
Nebraska 10–3488	8	1.23	82	27.7	0.91	103	23.3	1.07	90
Ohio	9	1.22	81	33.3	0.78	89	33.3	1.00	84
Iowa	10	1.41	94	—	0.87	99	27.1	1.14	96
North Dakota	11	1.48	99	—	0.88	100	27.9	1.18	99
Montana	12	1.38	92	—	—	—	—	—	—
Kansas Achenbach	13	1.50	100	—	.088	100	28.5	1.19	100
North Dakota	14	1.53	102	—	—	—	—	—	—
Parkland	15	1.70	113	22.2	0.86	98	18.7	1.28	108
North Dakota D608	16	1.51	101	—	1.03	117	30.2	1.27	107
Utah B-11	17	—	—	—	0.84	95	29.7	—	—
Utah B-12	18	—	—	—	0.88	100	25.4	—	—
Canadian certified	19	—	—	—	0.85	97	31.0	—	—
Russia	20	—	—	—	1.02	116	5.2	—	—
Russia	21	—	—	—	0.90	102	19.6	—	—
Russia	23	—	—	—	0.93	106	28.0	—	—
North Dakota	25	—	—	—	0.89	101	28.8	—	—
Alfalfa	—	—	—	—	0.84	95	0	—	—

dry matter for five strains analyzed for both the 1940 and 1942 seedings is given in Table 6.

From Table 6 it will be noted, the percentage dry matter of bromegrass when grown alone was very much the same as when grown with alfalfa. All strains failed to head out in the second cutting and all contained lower percentages of dry matter. Although the Kansas strain is not included in Table 6, its dry matter content for 1943, 1944, and 1945 averaged 33.8% when grown alone and was identical with the Nebraska strain. When grown with alfalfa, the dry matter

content of the Kansas and Nebraska strains from the first cutting was 35.5 and 35.1%, respectively. From the second cutting these same strains contained 28.1 and 26.1% dry matter, respectively. The dry

TABLE 5.—*Total yields of bromegrass and alfalfa when grown in mixture, average production per season.*

Strain	Strain No.	1940 seedings		1942 seedings		Both seedings	
		Tons per acre	% of Kansas	Tons per acre	% of Kansas	Tons per acre	% of Kansas
Nebraska 90	1	3.22	86	—	—	—	—
North Dakota D607	2	3.03	82	—	—	—	—
North Dakota D22	3	3.23	87	—	—	—	—
Montana	4	3.12	84	—	—	—	—
Saskatchewan	5	3.07	82	—	—	—	—
Michigan	6	3.07	82	2.83	90	2.95	86
North Dakota bulk	7	3.23	87	3.02	96	3.13	91
Nebraska 10-3488	8	3.28	88	3.13	99	3.21	94
Ohio	9	3.10	83	2.77	88	2.93	85
Iowa	10	3.25	87	2.73	87	2.99	87
North Dakota	11	3.35	90	2.62	83	2.98	87
Montana	12	3.12	84	—	—	—	—
Kansas Achenbach	13	3.72	100	3.15	100	3.43	100
North Dakota	14	3.40	91	—	—	—	—
Parkland	15	3.37	91	2.62	83	2.99	87
North Dakota D608	16	3.32	89	2.95	94	3.13	91
Utah B-11	17	—	—	2.73	87	—	—
Utah B-12	18	—	—	2.97	94	—	—
Canadian certified	19	—	—	2.73	87	—	—
Russia	20	—	—	2.45	78	—	—
Russia	21	—	—	2.47	78	—	—
Russia	23	—	—	2.73	87	—	—
North Dakota	25	—	—	2.75	87	—	—
Alfalfa	—	—	—	2.28	72	—	—

TABLE 6.—*Percentage dry matter of bromegrass strains when grown alone and with alfalfa and from first and second cuttings when grown with alfalfa.*

Strain	Strain No.	Percentage dry matter in bromegrass			
		Six first cuttings		Four 1st and 2nd cuttings, comparable years	
		Alone	With alfalfa	1st cutting	2nd cutting
Michigan	6	33.3	34.3	34.1	31.2
North Dakota	7	34.1	34.3	34.8	29.8
Nebraska 10-3488	8	35.6	35.9	35.6	27.4
Ohio	9	34.4	35.3	35.9	30.0
Parkland	16	33.8	33.6	33.7	27.2
	Average	34.2	34.7	34.4	29.1

matter content of these two strains from first cuttings would indicate they were somewhat earlier in maturity than most of the other strains, especially Russian strain 20 which averaged 26.8% dry matter when grown in mixture and 29.9 when grown alone. Yields of hay per acre were directly influenced by the percentage of dry matter.

PERCENTAGE OF BROMEGRASS IN MIXTURES

Several factors influence the percentage of bromegrass in an alfalfa bromegrass mixture. Data in Table 3 show that strain of bromegrass and seasonal conditions after seeding are two of these factors. From the 1940 trials, Parkland averaged much less bromegrass (28.7%) and a higher amount of alfalfa (71.3%) than other strains analyzed. In the 1942 trials, strain 20 from Russia was much lower in bromegrass (19.6%) than any other strain. Parkland was again lower (56.6%) than most strains. It will also be noted that percentage of bromegrass in the mixture is much higher from 1942 than from 1940 seedings even though the strains, month of planting, rate of seeding, and other factors, excepting seasonal conditions (year of seeding), were the same. Several strains, including Michigan, Ohio, Iowa, Nebraska, and Kansas, were very similar in percentage of bromegrass.

Mixing bromegrass with alfalfa reduced the yield of the latter regardless of strain. Plots of alfalfa from mixtures were as high for the Kansas and Nebraska strain as for other strains excepting Parkland and those from Russia. No bromegrass-alfalfa mixture regardless of strain produced as much alfalfa as plots of alfalfa grown in pure stand.

Table 4 shows the percentage of bromegrass in the second cutting of the mixtures for the two seeding trials. When data in Tables 3 and 4 are compared, it will be noted that mixtures contained a higher percentage of bromegrass in the first than in the second cutting. The percentage bromegrass in the second cutting was very similar for the two seedings even though these seedings differed considerably in percentage of bromegrass in first cuttings. Several strains when in mixture with alfalfa produced as much alfalfa from the second as from the first cutting.

TILLERS AND LEAVES

Since both the Nebraska 10–3488 and Achenbach (Kansas) strains appeared to be more stemmy than other strains, especially the first year, the percentage and yield of tillers and leaves[4] were determined as reported in Table 7. Data show that the percentage of tillers and leaves was as high for these strains as for other strains and the yield somewhat higher than most strains. The percentage of leaves and tillers increased considerably after the first year, as shown in Fig. 1. The same figure shows that in the third year more stems and heads (lower percentage leaves and tillers) were produced when the bromegrass was in mixture with alfalfa.

PROTEIN AND FIBER CONTENT

The percentage and yield of protein in different bromegrass strains and in alfalfa is given in Table 8. All strains were much higher in per-

[4]This consisted of all tillers not heading plus leaf blades striped from stems headed.

centage of protein in the second than in the first cutting. The protein content of both bromegrass and alfalfa was slightly higher when

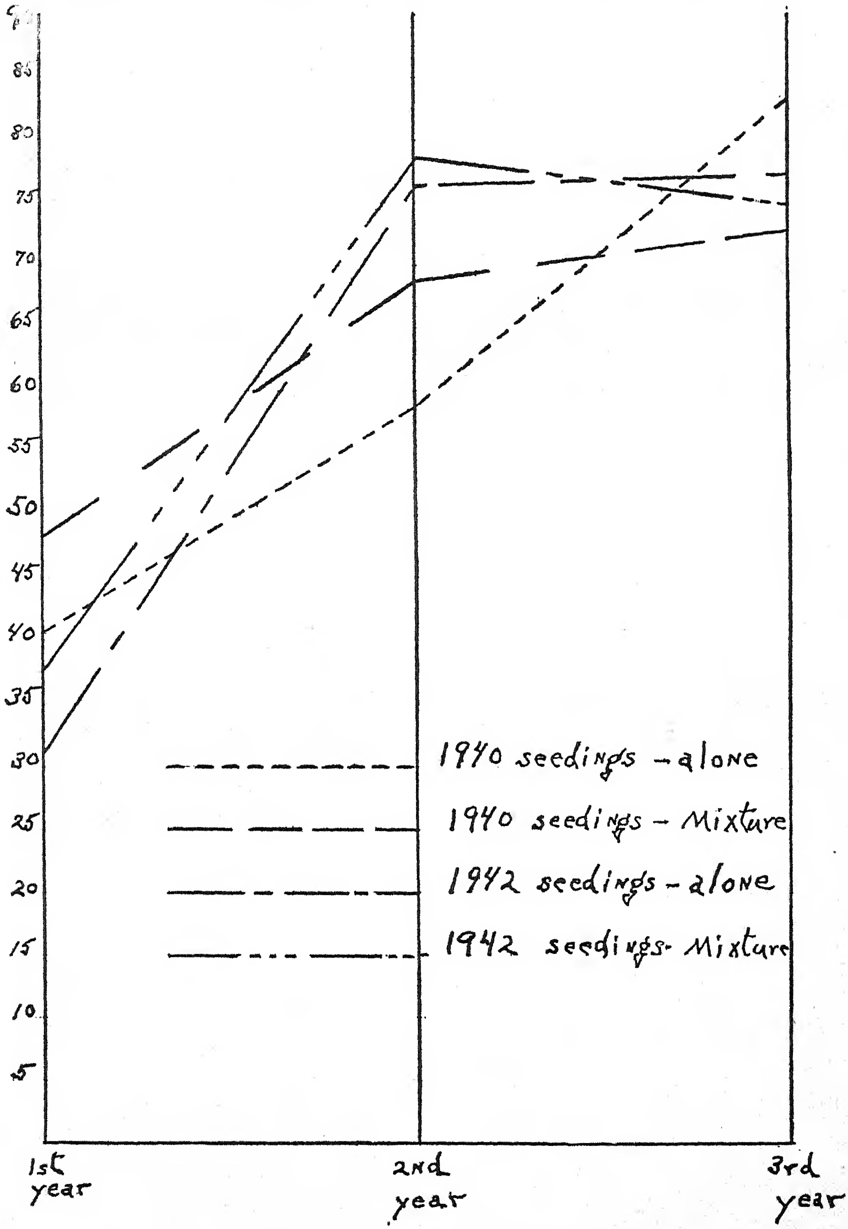

FIG. 1.—Average percentage leaves and tillers of bromegrass strains when grown alone and in mixture with alfalfa.

TABLE 7.—*Bromegrass strains alone and in mixture with alfalfa in percentage and pounds per acre of leaves and tillers, first cutting.*

Strain source or variety	No.	Grown alone				Grown with alfalfa			
		1940 seeding		1942 seeding		1940 seeding		1942 seeding	
		%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.
Michigan	6	51.1	1,416	53.0	1,664	65.6	1,470	59.4	1,938
North Dakota	7	50.3	1,375	62.2	1,979	52.3	1,049	68.8	2,921
Nebraska 10–3488	8	58.3	2,422	56.3	1,994	67.0	1,804	64.8	2,435
Ohio	9	60.5	1,702	53.4	1,676	66.0	1,658	62.4	2,048
Iowa	10	—	—	47.4	1,499	—	—	54.0	1,851
North Dakota	11	—	—	41.0	1,124	—	—	48.4	1,494
Kansas Achenbach	13	—	—	59.4	2,150	—	—	69.5	2,608
Parkland	15	61.3	1,533	60.0	1,633	67.7	850	55.8	1,425
North Dakota D608	16	—	—	56.7	1,859	—	—	64.2	2,190
Utah B-11	17	—	—	39.2	1,363	—	—	47.8	1,684
Utah B-12	18	—	—	49.3	1,795	—	—	51.7	1,827
Canadian certified	19	—	—	52.3	1,359	—	—	50.1	1,821
Russia	20	—	—	64.2	1,400	—	—	64.6	553
Russia	21	—	—	78.1	2,166	—	—	71.5	1,414
Russia	23	—	—	75.6	1,481	—	—	71.8	1,967
North Dakota	25	—	—	41.8	1,213	—	—	54.3	1,657

grown in mixture than when either were grown alone. In second cuttings, the percentage of protein in the bromegrass was equal to that of the alfalfa. Although the Kansas strain produced more total tonnage of hay per acre than most strains (Table 3), it did not produce more protein (Table 8).

TABLE 8.—*Percentage of protein in bromegrass strains and average yield of protein in pounds per acre, 1943–45.*

Strain source or variety	Strain No.	Alone, % protein, 1st cutting	In mixtures			
			Percentage protein		Lbs. protein per acre	
			1st cutting	2nd cutting	Av. per cutting	% of Kansas
Michigan	6	8.01	9.12	17.67	391	95.4
Nebraska 10–3488	8	7.04	8.11	16.52	414	101.0
Kansas Achenbach	13	7.69	7.97	15.62	410	100.0
Parkland	15	8.97	9.40	19.00	399	97.3
North Dakota D608	16	7.74	9.10	17.18	414	101.0
Utah B-12	18	7.48	8.46	17.11	434	105.9
Russia	20	11.81	16.24	22.40	486	118.5
Av. of bromegrass		8.39	9.77	17.93		
Alfalfa alone			17.31	18.68	440	107.3
Alfalfa in mixture			19.39	19.13		

Table 9 gives the percentage of fiber in the different strains. In general, fiber was higher in the Nebraska and Kansas strains, and all strains contained a higher percentage of fiber in the first than in the second cuttings. Most strains showed a higher fiber content when grown with alfalfa than when grown alone.

TABLE 9.—*Percentage of fiber in bromegrass strains from first and second cuttings.*

Strain source or variety	Strain No.	Percentage fiber in bromegrass when grown		
		Alone, 1st cutting	In mixture with alfalfa	
			1st cutting	2nd cutting
Michigan	6	33.6	35.9	27.7
Nebraska 10–3488	8	36.1	38.3	30.0
Kansas Achenbach	13	34.5	37.1	30.4
Parkland	15	33.4	35.6	27.0
North Dakota D608	16	34.7	35.9	28.5
Utah B-12	18	35.5	36.3	29.0
Russia	20	33.8	33.6	28.4
Average		34.5	36.1	28.7
Alfalfa alone			33.6	25.3
Alfalfa in mixture			33.1	26.3

AGGRESSIVENESS OF STRAINS

Several of the strains were planted in nursery rows 36 inches apart and observed for their aggressiveness the following summer. The three most aggressive strains, based on ability and rapidity of spreading, were Achenbach, Nebraska 10–3488, and Russian 20. When grown in mixture with alfalfa, this greater aggressiveness did not result in an increase in percentage of bromegrass in the mixture, as shown in Table 3. Although Russian 20 strain was very aggressive, its total yield was the lowest of all strains tested. The Michigan strain and a number of strains from Canada were least aggressive. When the nursery rows were fall plowed and planted to corn the following spring, no strain regardless of its aggressiveness was troublesome as a weed in the corn. Fig. 2 shows the comparative aggressiveness of the Achenbach, Parkland, and Iowa strains.

SUMMARY

1. Data are presented to show the relative value of several strains of bromegrass when grown alone and in mixture with alfalfa. Total yield of hay, percentage of the mixture as bromegrass, protein and fiber, and percentage of tillers and leaves are reported.

2. Bromegrass strains seeded in early August produced maximum yields the following year when seeded alone. In mixture, the plots were still very productive in the third year.

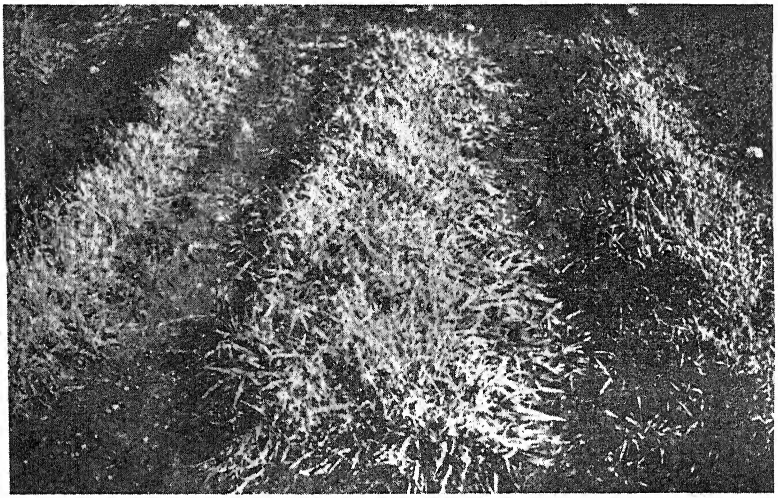

FIG. 2.—*Left,* Parkland; *center,* Kansas Achenbach; *right,* Iowa.

3. Mixtures of bromegrass and alfalfa yielded more than either crop planted in pure stand.
4. Differences in total yield between bromegrass strains were greater when strains were grown alone than when grown in mixtures with alfalfa.
5. Average percentage of leaves and tillers of bromegrass strains when grown alone and in mixture with alfalfa increased after the first harvest year.
6. The percentage of bromegrass in alfalfa-bromegrass mixtures was lower from the second than from the first cutting.
7. Bromegrass strains when grown alone failed to produce a second cutting.
8. Percentage of protein in the bromegrass was twice as high from the second as from the first cuttings.
9. The association of the bromegrass with the alfalfa increased slightly the percentage of protein of the bromegrass regardless of strain.
10. With one exception, bromegrass strains in alfalfa mixtures contained a higher percentage of fiber than when grown alone.
11. After the first harvest year, bromegrass produced more heads per plot when grown in mixture with alfalfa than when grown alone.
12. Alfalfa in pure stands yielded more than bromegrass regardless of strain of the latter, except in the first harvest year.
13. Kansas and Nebraska strains were earliest while Russian strains were latest in maturity.
14. Growing bromegrass and alfalfa in mixture reduced the acre yield of each individually as compared with yields of these crops when each was grown alone.
15. The most aggressive strains were from Kansas, Nebraska, and

Russia and the least aggressive strains were from Michigan and Canada.

16. The Kansas Achenbach strain produced the highest total yield of dry hay per acre but did not produce the most protein per acre.

CONCLUSIONS

1. The percentage of bromegrass in an alfalfa-bromegrass mixture is probably more important in Michigan than choice of bromegrass strain.

2. Percentage of bromegrass in the mixture was influenced by strain and year of planting insofar as these trials were concerned. Other factors include rate of seeding of the bromegrass, soil conditions favorable to alfalfa, management of the field after the mixture is established, age of stand, amount of alfalfa wilt, and winter killing of the alfalfa.

3. Seed yields of bromegrass from an alfalfa bromegrass mixture should be highest the first harvest year. In the third year, seed yields of bromegrass will probably be higher from mixtures than from bromegrass in pure stands if no nitrogenous fertilizer is applied.

4. The increased fiber content of bromegrass from alfalfa mixtures was probably due to the increased stem production and is in line with the statement on seed production.

5. The nitrogen supplied by the alfalfa and utilized by the bromegrass when the two were grown in combination very probably was the cause of higher production in old stands, more growth of bromegrass in second cuttings, and more stems and hence greater possibilities of seed production of the bromegrass.

6. The decrease in protein content of the alfalfa when grown alone as compared with its protein content when grown in mixture with bromegrass was probably due to a greater loss of leaves when grown alone.

7. With good plowing, no strain tested should prove so aggressive that control would be a problem in Michigan.

8. In testing strains of bromegrass for Michigan it would seem advisable to plant them in mixture with alfalfa.

9. Any change in bromegrass strain used in Michigan probably should be from the Michigan to the Achenbach or Nebraska 10–3488 strains.

Effect of Soil Aggregates on Water Movement in Two Calcareous Soils[1]

D. S. HUBBELL[2]

IN 1897, Briggs (2)[3] proposed that the movement of water through soil is dependent on the number and size of the pore spaces. Subsequent investigations have developed the theoretical relation existing between soil structure and pore space (1). In spite of the evidence amassed since 1897, the practical relation of water movement to the porosity due to soil structure is not clearly understood. Perhaps the first to realize fully that soil structure plays an important role in maintaining soil porosity was Dojarenko (5). Dojarenko segregated aggregates of various sizes and determined the porosity of the different size groups. On the basis of this and related studies, it has been recognized that soil aggregation increases porosity and, as a result, the movement of water; but in certain problem soils neither the extent of aggregation nor the effect of size, amount, or kind of aggregates on water movement is known.

In the present studies, the relation of amount and size of soil aggregates to water movement in two Southwestern problem soils was investigated. In addition, certain phases of microbiological influences on aggregation and water movement in the two soils were studied.

METHODS

Two soils, Gila clay and Tucumcari sandy loam, were used in the present study. Sufficient amounts of the two soils were collected from the surface 6-inch layer to last out the study. They were air dried and stored until used. These soils have been described in a previous paper (4).

To determine the relation of the amount of aggregation and the size of the aggregates to percolation and capillary rise of water, soil mixtures were used in which the amount and the size of aggregates were controlled. From each of the two soils, aggregates of the following size ranges were separated by the wet-sieve method (6): 0.25 to 0.59 mm, 0.59 to 1.19 mm, 1.19 to 2.00 mm, and 2.00 to 2.38 mm. They were then air dried and resized on dry sieves. Portions of the two base soils were ground and passed through an 80-mesh (0.17 mm) sieve. Mixtures of the ground soils with each size of aggregate and with mixed aggregates were made up in the following proportions:

Weight of aggregates, grams	Weight of ground soil, grams	Total weight of sample, grams
0	100	100
15	85	100
30	70	100
45	55	100
60	40	100
75	25	100
100	0	100

In the series involving the use of mixed aggregates, the aggregate portion consisted of equal parts by weight of the four sizes of aggregates.

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[1]Contribution of the Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with Department of Agronomy, New Mexico Agricultural Experiment Station, State College, N. M. Received for publication March 29, 1947.

[2]Research Project Supervisor, Soil Conservation, Service

[3]Figures in parenthesis refer to "Literature Cited", p. 770.

After thorough mixing, each 100-gram sample was put into a 3.5-cm×20-cm filter tube that contained a filtering base consisting of a thin layer of glass wool under a 2.5-cm column of 1-mm quartz sand. The soil mixtures, in quadruplicate, were gently firmed with a flat-bottomed tube. The height of the soil columns varied from 11 cm in the ground soil to 13 cm in the 100% 2-mm aggregates. The sample tubes were set in tap water, with the water level at the juncture of the sand and the soil column; and the rate of capillary rise was recorded. The soil columns were then compressed to a height of 9 cm, and percolation rates were determined by the method of Slater (6) except that final readings were not taken until constant values had been observed. Such constant rates were usually reached after about 3 hours of treatment.

A similar series of mixtures was used in which quartz sand or river gravel, sieved to sizes corresponding to those of the aggregates, took the place of aggregates. Volumes of sand were used instead of weights. Aggregates of the different sizes were weighed in the amounts required for the various mixtures, and the volumes were determined. Portions of the sands were then measured out and mixed with weighed amounts of ground soil corresponding to those used for the aggregate-ground soil mixtures. Only Gila clay was used for this series.

The relation of microorganisms and their respective kinds of aggregates to percolation was studied in a third series using both Gila clay and Tucumcari sandy loam. The soils were ground and passed through an 80-mesh sieve to destroy all aggregates above 0.17 mm. They were then sterilized, and inoculated with fungi, actinomycetes, or bacteria. The technique of sterilization and inoculation has been previously published (4). After inoculation, the cultures were incubated for 30 days at 26° C, and percolation rates and percentage of aggregation were determined.

Nutrient media designed to favor certain types of microorganisms were added to a uniform series of unsterilized soils, and the ultimate effects on soil aggregation and water percolation were observed. The following nutrient media were used: Fred and Waksman's (3) sodium nitrate sucrose medium No. 16 for fungi, sodium albuminate medium No. 5 for bacteria, and soluble starch medium No. 36 for actinomycetes. The moisture content after application of the media was approximately that of field capacity. Moisture was supplied to the check soil as a solution of the components of the media from which the source of carbon had been omitted. After 30 days' incubation at 26° C, percolation rates and percentage of aggregation were determined.

RESULTS AND DISCUSSION

EFFECT OF QUANTITY AND SIZE OF AGGREGATES ON CAPILLARY RISE

Capillary rise was much more rapid in the Tucumcari sandy loam than in the Gila clay (Table 1). The effect of aggregation in the 0.25-mm aggregate samples was similar in both soil types. The rate began to increase over that of the checks in the 15% aggregate samples and rose nearly uniformly as the percentage of aggregation increased. A similar but less apparent trend occurred in the 0.59-mm sets, but the rate of increase began at the 45% level. In the two larger aggregate groups of the Gila clay, a pronounced peak was observed at the 75% aggregation point. This peak was observed also in the two larger aggregate groups of the lighter soil, but at the 60% level. Except in the 75% aggregate samples, there was no effect of the 2.00-mm aggregates on capillary rise of water in the Gila soil. In Tucumcari sandy loam, on the other hand, there was a definite retarding effect above 60% of aggregation.

EFFECT OF QUANTITY AND SIZE OF AGGREGATES ON PERCOLATION

The data in Table 1 indicate that in both soils the amount of aggregation and the size of the aggregates affected the rate of percolation.

TABLE 1.—*The effect of quantity and size of soil aggregates on percolation and capillary rise.*

Size of aggregates*	Percentage of aggregates by weight	Tucumcari sandy loam		Gila clay		Sand and gravel plus ground Gila clay	
		Capillary rise, cm per minute	Percolation, cc per hour	Capillary rise, cm per minute	Percolation, cc per hour	Capillary rise, cm per minute	Percolation, cc per hour
2.00 mm	0	0.46	12.3	0.05	0.9	0.05	1.1
	15	0.47	13.0	0.05	1.0	0.05	0.9
	30	0.50	12.1	0.05	1.0	0.05	0.8
	45	0.55	14.1	0.05	1.0	0.05	1.0
	60	0.55	31.1	0.05	1.1	0.12	2.2
	75	0.41	57.2	0.10	2.1	0.16	1,800
	100	0.29	77.6	0.05	13.0	—†	12,000
1.19 mm	0	0.43	11.9	0.05	0.9	0.05	0.8
	15	0.43	12.0	0.05	1.0	0.05	0.8
	30	0.43	13.6	0.05	0.9	0.06	0.8
	45	0.55	15.1	0.05	1.0	0.06	0.9
	60	0.77	30.1	0.06	1.7	0.17	2.4
	75	0.66	43.8	0.10	3.3	0.37	600
	100	0.58	57.6	0.07	7.0	—†	8,500
0.59 mm	0	0.50	12.1	0.05	0.9	0.05	0.9
	15	0.55	13.3	0.05	0.9	0.05	0.9
	30	0.55	12.4	0.05	0.9	0.06	0.8
	45	0.66	15.3	0.05	1.1	0.07	0.9
	60	0.90	21.6	0.06	1.9	0.19	2.0
	75	1.11	30.8	0.19	3.6	0.50	20.5
	100	1.00	42.8	0.08	4.4	—†	5,800
0.25 mm	0	0.50	11.8	0.05	1.0	0.05	0.8
	15	0.55	11.6	0.05	1.1	0.06	1.1
	30	0.71	16.5	0.07	1.5	0.10	1.3
	45	0.83	16.4	0.10	1.8	0.16	1.6
	60	1.66	29.9	0.16	2.3	0.31	3.0
	75	2.50	46.8	0.18	4.2	0.59	13.0
	100	3.33	45.7	0.91	8.6	0.77	2,400
Mixture of all sizes in equal proportions	0	0.50	12.0	0.05	1.1	0.05	1.0
	15	0.50	12.7	0.05	1.0	0.05	1.1
	30	0.43	13.5	0.05	0.8	0.07	1.1
	45	0.46	15.0	0.05	1.4	0.10	1.9
	60	0.37	19.7	0.06	2.4	0.18	2.2
	75	0.30	18.0	0.06	4.0	—	—
	100	0.25	26.2	0.06	9.0	—	—

*Aggregate sizes designated by minimum with size range (2.38 to 2.00, 2.00 to 1.19, 1.19 to 0.59, 0.59 to 0.25 mm).

†Water had reached an apparent equilibrium about ⅛ the height of the column at the end of 24 hours.

Although the rates of percolation differed widely between the two types of soil, the shapes of the curves drawn from these data (Fig. 1) are similar. In both the light- and the heavy-textured soils, percolation was most rapid in the samples with high percentages of aggregates, the highest being in those with 100% of 2-mm units. Percola-

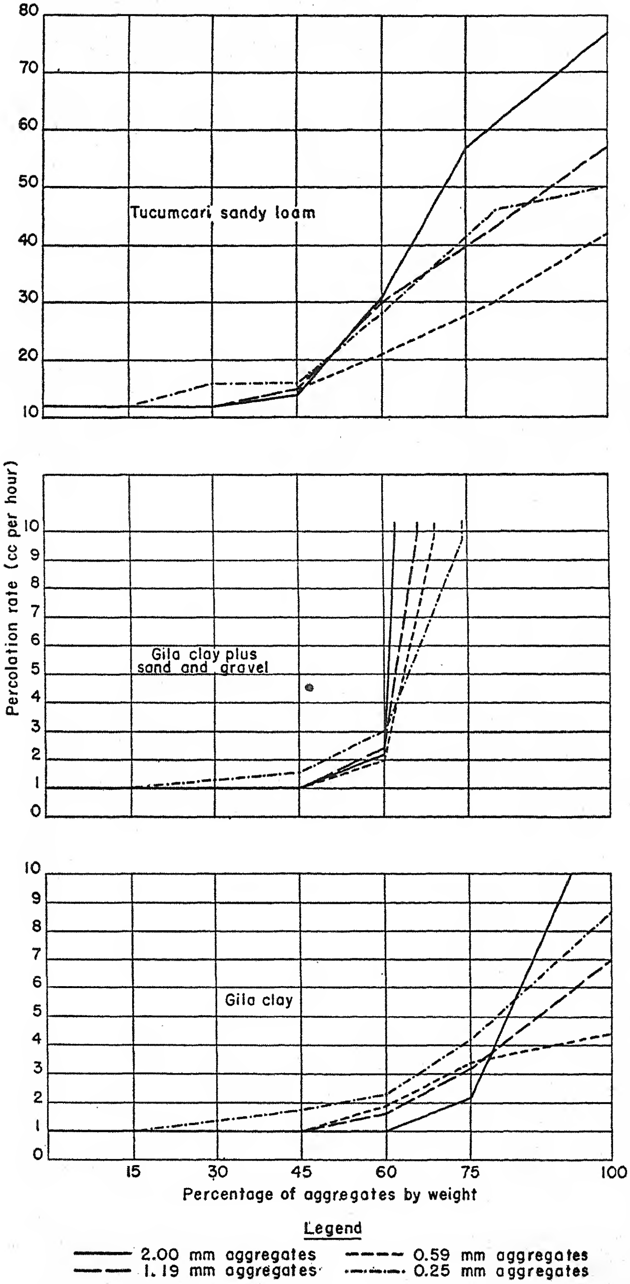

FIG. 1.—Effect of aggregation on rate of percolation.

tion was least affected by the 0.59-mm aggregates. In the Tucumcari sandy loam, percolation in the samples containing the three larger sizes of aggregates was not affected until the amount of aggregation reached 45%, and from this point the rise in rate was fairly uniform. The rate of percolation in the set of samples containing 0.25-mm aggregates began to increase just above the 15% mixture, increased sharply between 45% and 80%, and then leveled off. In the Gila clay soil-aggregate mixtures, the percolation rate in those with 2-mm aggregates began increasing between 60% and 75% of aggregation and increased sharply above 75%. The rates in the samples containing 1.19-mm and 0.59-mm aggregates increased fairly uniformly from the 45% to the 100% aggregate samples. The increase in the samples with 0.25-mm aggregates became apparent above the 15% mixture, became sharp above 60% of aggregation, and began to level off at 75%.

Comparison of the percolation data in Tables 1, 2, and 3 indicates that, for comparable percentages of aggregation, a mixture of sizes up to 2 mm was more effective in increasing percolation rate than were the admixtures of aggregates of restricted size ranges. This point is further emphasized by the fact that an unground and unsifted soil with 38% aggregation had a more rapid percolation rate than that observed in ground soil with admixtures of 60% or less of aggregates of restricted size range (Tables 2 and 3). This difference in behavior is probably attributable to the presence of an important percentage of aggregates less than 0.25 mm diameter in the unground soil.

The effect of substituting sand or gravel for aggregates may be observed in Table 1. The results show that the effect of admixtures of water-stable aggregates on percolation of water in fine-textured soil was similar to that of lightening the texture by adding the same volume of sand or gravel in the same size class. Although, probably owing to their porous character, the aggregates were not so effective in speeding up percolation in the 75% and the 100% samples, the effect of adding 60% or less of aggregates or sand was nearly the same. Thus, in a tight soil such as the Gila clay, the effect of maintaining favorable structure, even as little as 38% (Table 1) should be equivalent, in terms of percolation, to the addition of large amounts of sand.

EFFECT OF MICROORGANISMS ON PERCOLATION

Inoculation of sterilized soil, which lacked aggregates above 0.17 mm, with fungi, actinomycetes, or bacteria slowed the rate of percolation (Table 2). Since the percentage of aggregation was too low to produce an effect on percolation (cf. Tables 1 and 2), the reason perhaps lies in the growth of microorganisms. Table 3 presents data illustrating the effects of adding culture media to unsterilized soil that had passed through a 2.00-mm sieve. Each of these media was intended to stimulate the growth of a different group of organisms. All of them depressed the rate of percolation as compared to that of the check soils. This cannot be accounted for by differences in percentages of aggregates. A possible explanation may be drawn from the photomicrographs of Fig. 2, which show aggregates from the check and from one of the soils that received an added source of carbon. The

TABLE 2.—*The effect of microorganisms on aggregate formation and percolation.*

Soil treatment*	Gila clay, aggregate diameters in mm†						Tucumcari sandy loam, aggregate diameters in mm†					
	2.00, %	1.19, %	0.59, %	0.25, %	Total, %	Rate of percolation, cc per hour	2.00, %	1.19, %	0.59, %	0.25, %	Total, %	Rate of percolation, cc per hour
Sterilized plus fungi	1.14	0.21	0.21	0.09	1.65	1.0	1.91	0.40	0.12	0.05	2.48	12.4
Sterilized plus fungal medium	0.00	0.00	0.00	0.00	0.00	1.8	0.00	0.00	0.00	0.00	0.00	18.0
Sterilized plus actinomycetes	0.55	0.20	0.28	0.06	1.09	1.3	0.38	0.11	0.07	0.08	0.64	16.3
Sterilized plus actinomycete medium	0.00	0.00	0.00	0.00	0.00	1.7	0.00	0.00	0.00	0.00	0.00	18.0
Sterilized plus bacteria	0.00	0.00	0.00	0.04	0.04	1.1	0.00	0.00	0.02	0.04	0.06	14.8
Sterilized plus bacterial medium	0.00	0.00	0.00	0.00	0.00	1.9	0.00	0.00	0.00	0.00	0.00	18.3
Sterilized plus mixed culture	0.91	0.25	0.22	0.19	1.57	1.7	0.63	0.38	0.41	0.24	1.66	16.8
Sterilized plus mixed culture medium	0.00	0.00	0.00	0.00	0.00	2.1	0.00	0.00	0.00	0.00	0.00	22.0
Sterilized plus soil extract	1.18	0.37	0.33	0.17	2.05	1.9	1.62	0.90	0.74	0.35	3.61	9.8
Sterilized plus sterile soil extract	0.00	0.00	0.00	0.00	0.00	2.0	0.00	0.00	0.00	0.00	0.00	18.5
Sterilized plus sterile distilled water	0.00	0.00	0.00	0.00	0.00	2.1	0.00	0.00	0.00	0.00	0.00	16.8
Ground plus tap water	0.45	0.14	0.12	0.09	0.80	0.4	0.06	0.16	0.09	0.13	0.44	9.5
Crushed plus tap water	4.34	7.32	12.01	13.38	37.05	4.5	1.07	7.99	12.08	9.89	31.03	21.0

*Crushed = passed through a 2-mm sieve; Ground = passed through a 0.17-mm sieve. All sterilized soils were ground.
†Aggregate sizes designated by minimum within size range (2.38 to 2.00, 2.00 to 1.19, 1.19 to 0.59, 0.59 to 0.25 mm).

TABLE 3.—*The effect of sucrose, starch, and egg albumin on aggregation and percolation.*

Soil treatment*	Gila clay, aggregate diameters in mm†						Tucumcari sandy loam, aggregate diameter in mm†					
	2.00, %	1.19, %	0.59, %	0.25, %	Total, %	Rate of percolation, cc per hour	2.00, %	1.19, %	0.59, %	0.25, %	Total, %	Rate of percolation, cc per hour
Tap water	4.34	7.32	12.01	13.38	37.05	4.5	1.07	7.91	12.47	9.79	31.33	32.8
Tap water plus minerals‡	2.38	8.57	15.21	12.82	38.98	3.0	3.69	8.68	13.65	10.49	36.31	23.5
Sucrose medium	4.57	8.06	10.60	10.58	33.81	1.2	3.61	7.17	10.28	7.69	28.75	7.2
Soluble starch medium	1.84	7.58	13.39	13.14	35.95	1.0	3.54	9.39	14.47	8.65	36.05	7.9
Egg albumin medium	2.41	8.84	15.34	12.13	38.72	1.5	2.65	9.34	13.48	9.88	35.35	12.8

*Air-dry soil crushed through a 2.00-mm sieve.
†Aggregate sizes designated by minimum within size range (2.38 to 2.00, 2.00 to 1.19, 1.19 to 0.59, 0.59 to 0.25 mm).
‡Mineral components of the nutrient media.

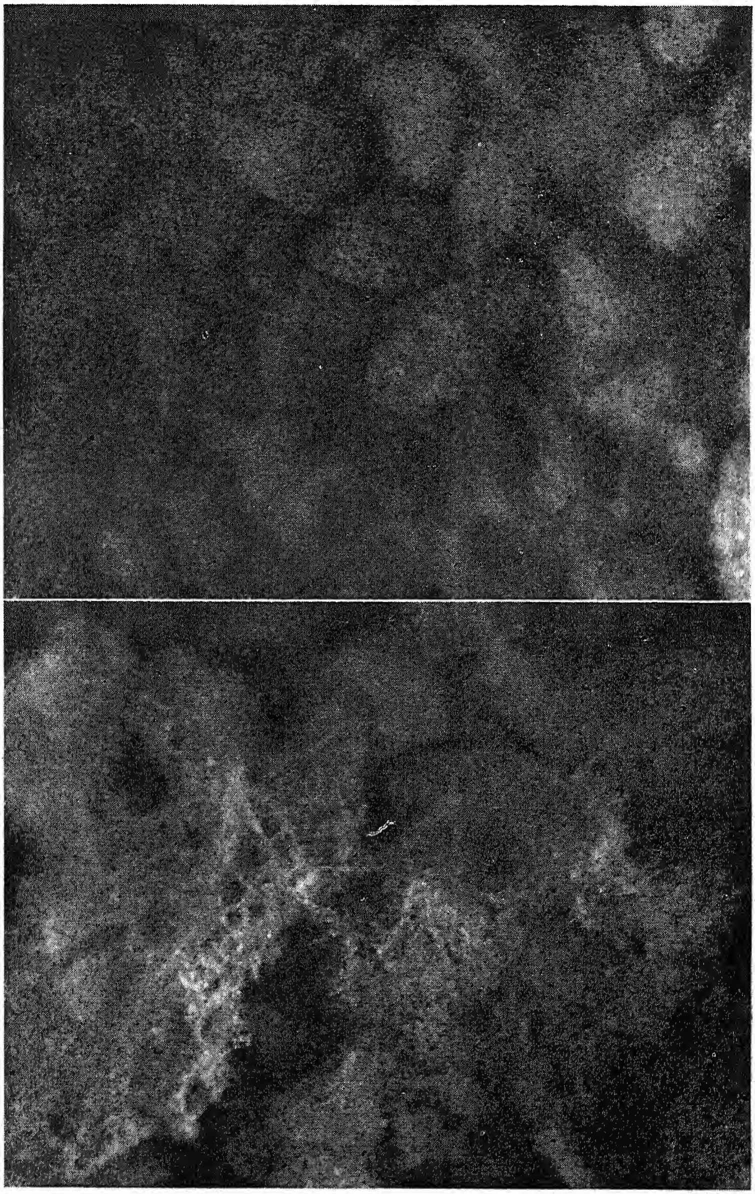

FIG. 2.—Photomicrographs of aggregates from the check soil and from a soil that received an added source of carbon. *Above*, normal 0.59 mm Gila clay aggregates after 30 days' incubation (XII); *below*, 0.59 mm Gila clay aggregates after 30 days' incubation with sucrose medium (XII).

decrease in percolation rate appears to have been due to a displacing of the equilibrium between the three groups of organisms.

SUMMARY

Laboratory investigations on the movement of water as affected by controlled percentages of soil aggregates and by soil flora were carried out with the use of Gila clay and Tucumcari sandy loam soils.

Mixtures of pulverized soils, with different percentages of water-stable soil aggregates of known size ranges (0.25 to 0.59 mm, 0.59 to 1.19 mm, 1.19 to 2.00 mm, and 2.00 to 2.38 mm) were studied.

Capillary rise was steadily increased only when the aggregate population was limited to small sizes (0.25 mm to 0.59 mm) and in quantities of not less than 15% of the total weight. When the aggregate population consisted of large aggregates up to 2.38 mm in diameter, the rate of capillary rise began to increase only when the total aggregate weight amounted to 45 to 75% of the total soil weight. Beyond 75% there was a tendency for capillary rise to be retarded.

Percolation rates in both soils were increased with as little as 15% aggregation when the aggregates were small (0.25 to 0.59 mm). In general, as the percentage of small aggregates increased, the percolation rate increased. Large aggregates up to 2.38 mm in diameter had no effect on percolation until they comprised 60 to 75% of the total soil weight. Although the larger aggregates were slow to affect percolation, the rate was much faster than with the smaller aggregates.

When sand or gravel was substituted for either a selected or normal aggregate population, water movement was affected in the same manner, up to 75% of the total soil weight. Beyond this point, capillary rise was stopped and percolation was markedly accelerated.

Additions of nutrient media to unsterilized soil produced no effect on total aggregation but decreased the rate of percolation.

LITERATURE CITED

1. BAVER, L. D. Soil Physics. New York: John Wiley and Son, Inc. 1940. (Pages 160–164.)
2. BRIGGS, L. J. The mechanics of soil moisture. U.S.D.A. Bur. Soils Bul. 10. 1897.
3. FRED, E. E., and WAKSMAN, S. A. Laboratory Manuel for General Microbiology. New York: McGraw-Hill Book Co., Inc. 1928.
4. HUBBELL, D. S., and CHAPMAN, J. E. The genesis of structure in two calcareous soils. Soil Sci., 62:271–281. 1946.
5. KRAUSE, MARTIN. Russian investigations in the field of soil structure. Landw. Jahrb., 73:603–690. 1931.
6. SLATER, C. S., and BYERS, H. G. A laboratory study of the field percolation rate of soils. U. S.D.A. Tech. Bul. 232.

Inhibition of Azotobacter by Soil Actinomycetes[1]

LOUIS G. NICKELL AND PAUL R. BURKHOLDER[2]

THE purpose of the experiments reported here was to demonstrate the inhibition of growth of free-living, aerobic, nitrogen-fixing bacteria by actinomycetes isolated from soil and cultured in various kinds of media, including soils, fertilizers, and organic matter such as may be found commonly in agricultural areas. Although many inhibiting substances are now known to be produced by soil organisms growing in artificial laboratory media, almost nothing is known about the antibacterial activities of such organisms living in their natural environment. It was considered desirable, therefore, to investigate the inhibition of *Azotobacter* by soil actinomycetes grown not only in artificial media but also in soils and in cover crop materials under laboratory conditions which would simulate to a considerable extent the conditions which might be found in the field.

MATERIALS AND METHODS

A culture of *Azotobacter vinelandii*, kindly supplied by Dr. R. H. Burris, was used in these studies. Cultures of approximately 13,000 soil actinomycetes were isolated from many different regions of the United States and some foreign countries. The isolation of these soil organisms was accomplished by streaking a water suspension of the soil sample on nutrient agar plates. The composition of this isolation agar is as follows: Asparagine, 1.0 gram; glucose, 1.0 gram; $MgSO_4.7HO$, 0.2 gram; $CaCl_2$, 0.1 gram; KCl, 0.1 gram; NH_4H_2 PO_4, 1.5 grams; agar, 12.0 grams; and water, 1,000 ml. The pH was adjusted to 7.5 to 8.0. After actinomycetes had grown in the plates, spores were carefully picked from the small colonies and then transferred to Difco dextrose agar slants. These stock cultures were then tested for possible antagonistic activity against a number of different microorganisms by means of the agar streak-plate method. For results obtained with 23 selected cultures, see Table 1. The techniques used in the preliminary streak plate tests are similar to those discussed in the general antibiotic literature (6).[3] Actinomycetes which inhibited *E. coli* were selected as being of possible further interest in connection with the study of inhibition of *Azotobacter*. In order to select the most active actinomycete cultures for further study, streak-plate tests with *Azotobacter* were employed. The composition of the nutrient medium used is as follows: Difco nutrient agar, 18.4 grams; sucrose, 8.0 grams; NaCl, 5.0 grams; and water, 1,000 ml.

The technique consisted of inoculating spores of four different actinomycete cultures at four points near the edge of each agar plate. After a growth period of 4 days at 30° C a loopful of *Azotobacter* suspension in broth was streaked from the center of the plate outward to each of the actinomycete colonies. An illustration of the method is shown in Fig. 1.

In all cases where sterile media were used, the materials were autoclaved at 120° C for 15 minutes. The soil, cover crop materials, and fertilizers were obtained in or near New Haven Conn., for use as substrates. In some instances a small amount of "aerosol" was added to broth suspensions of actinomycete spores for the purpose of obtaining homogeneous inocula. Further details of methodology will be given in connection with the reports on individual experiments.

[1]Contribution from the Osborn Botanical Laboratory, Yale University, New Haven, Conn. Received for publication April 14, 1947.

[2]Graduate Student and Eaton Professor of Botany, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 779.

TABLE 1.—*Antibiotic activity of some actinomycetes which inhibit Azotobacter tested against representative types of microorganisms.**

Culture No.	Activity in streak plates					Activity in shaken cultures			
	Staph. aureus	*Escherichia coli*	*Mycobacterium* (ATCC 607)	*Candida albicans*	*Trichophyton gypseum*	*Staph. aureus*, complete	*E. coli*, complete	*E. coli*, partial	*Mycobacterium* (ATCC 607), complete
75	35	35	35	14	35	1.0	1.5	0	6.5
1043	18	12	25	10	0	4.0	2.5	0	2.5
1479	35	23	11	3	9	4.0	4.5	0	0
1489	23	16	35	0	18	3.0	2.0	2.5	10.0
1492	35	35	35	0	35	2.0	1.5	2.5	9.5
2303	35	16	16	9	2	4.0	1.5	0.5	1.5
2463	35	27	35	16	21	5.0	4.0	0	9.0
2500	35	28	25	11	18	3.5	2.5	0	6.5
3057	35	16	34	29	28	4.5	4.0	0	0
3511	17	16	26	10	20	2.0	2.0	5.0	12.0
3521	19	24	17	19	18	4.0	4.0	0	0
3644	35	18	26	30	24	4.0	4.0	0	0
3865	17	14	10	9	12	4.0	2.5	0	0
4328	35	20	35	27	20	2.0	2.0	0	0
4659	35	35	35	31	32	2.0	2.0	6.0	12.0
5376	22	20	28	14	7	1.0	1.5	1.5	4.0
5413	22	16	24	10	6	0	2.0	0	1.5
6238	32	26	35	0	0	0.5	0	1.5	9.0
7766	35	35	35	11	9	2.0	5.0	0	6.5
7791	35	35	35	14	35	2.5	5.0	0	12.0
8476	35	35	35	17	19	2.0	1.5	5.5	0
10462	35	20	35	31	28	1.5	2.0	0	0
10477	35	14	35	35	8	5.0	7.0	0	0

*Inhibition zones of streak plates and of shaken cultures are given in mm as in Table 2.

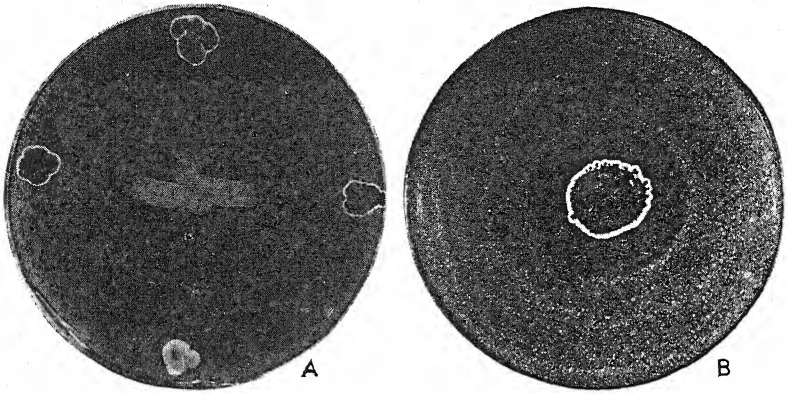

FIG. 1.—Inhibition of *Azotobacter* by actinomycetes. A, bacteria streaked on the surface of nutrient agar are inhibited by four colonies of actinomycetes; B, inhibition of *Azotobacter* around actinomycete 8476 cultured in soil and applied to an agar pour plate.

RESULTS

ACTIVITY OF ACTINOMYCETES GROWN IN STREAK PLATES AND IN SHAKEN, BROTH CULTURES

The results obtained with the streak-plate method of determining anti-*Azotobacter* activity of 25 selected cultures of actinomycetes are shown in Table 2. The zones of inhibition from the actinomycete colony to the edge of growth of *Azotobacter* are indicated in mm. The activities of these various cultures, as well as numerous others isolated from soils collected from various parts of the world, indicate wide-spread distribution of anti-bacterial actinomycetes in nature.

The cultures which were most active in streak plates were then cultivated in broth medium contained in culture tubes shaken in an inclined position on an oscillating shaker. The temperature was 30° C and the duration of the growth period was 4 days. The medium employed for the shaken cultures contained the following ingredients: Maltose, 10.0 grams; K_2HPO_4, 2.0 grams; NaCl, 5.0 grams; dehydrated corn steep, 10.0 grams; and water, 1,000, ml. The pH was adjusted to 7.0.

The tests for activity of the shaken broths against *Azotobacter* were made in sucrose nutrient agar pour plates. The composition of this agar is the same as that given above for the agar used in streak plate tests. The fermented media were tested with filter paper disks wet with the solution, and six disks were applied per agar plate. The standard filter papers, ½ inch in diameter, were obtained from Schleicher and Schuell, New York City. The incubation period for these tests was about 36 hours at 30° C. Tests of the shaken culture broths were made against *E. coli*, *S. aureus* and *Mycobacterium 607*, and the results are given in Table 1. The data for *Azotobacter*, presented in Table 2, show that a considerable number of shaken cultures inhibit growth of the nitrogen-fixing bacteria in nutrient agar plates. Whether such data give any true indication of the possible situation in nature remains to be demonstrated.

TABLE 2.—*Inhibition of Azotobacter vinelandii by soil actinomycetes grown in agar streak plates and in shaken broth cultures.*

Culture No.	Origin	Streak plates inhibition zone mm distance	Shaken broth tests inhibition zone mm radius*	
			Complete	Partial
75	New Guinea	27	5.0	2.5
1043	Chillicothe, Tex.	35	6.0	4.0
1479	Hermiston, Ore.	20	7.0	1.0
1489	Lubbock, Tex.	29	0	2.0
1492	Lubbock, Tex.	35	5.5	0
2303	Temple, Tex.	30	0	0
2463	Amherst, Mass.	31	7.0	0
2500	Amherst, Mass.	30	5.0	4.0
3057	Maxatawny, Pa.	19	7.0	2.0
3511	Falmouth, Mass.	33	7.0	5.0
3521	Madison, Wis.	17	6.0	1.0
3644	Lancaster, Pa.	35	5.5	2.5
3865	Colombia, Pa.	35	3.0	0
4328	Kingston, R. I.	35	3.0	1.5
4659	Tyler, Tex.	23	0	0
5376	South Laredo, Tex.	28	5.5	4.5
5413	Laredo, Tex.	21	3.5	1.0
6238	Clewiston, Fla.	35	6.0	5.0
6618	Weslaco, Tex.	35	0	1.0
7766	Gateway, Ark.	34	5.0	4.0
7791	Anson, Tex.	31	4.0	2.0
8476	Slaton, Tex.	32	9.0	2.0
10462	East Liverpool, O.	20	0	0
10477	Pittsburgh, Pa.	21	0	0
449	*Streptomyces griseus* (S. A. Waksman)	35	6.0	1.0

*The clear zone of inhibition measured radially from the edge of the filter pad to the first bacterial colonies is given as the complete zone in mm; the additional radial distance beyond the clear zone where partial inhibition was apparent is also indicated.

INHIBITORY ACTION OF ACTINOMYCETE CULTURES IN SOILS AND IN COVER CROP MATERIALS

For the purpose of determining the possible production of anti-*Azotobacter* substances in substrata resembling natural materials which might occur in the field, a number of soil treatments were set up as is indicated in Table 3. A poor clay soil was used alone and with single additions of leaf mold, cow manure, sheep manure, and two kinds of inorganic fertilizer. The amount of soil per flask was 4.5 grams in each treatment and additions of other materials were made at 10% of this amount. Each of these materials was covered with 20 ml of distilled water in 125-ml Erlenmeyer flasks, sterilized at 120° C for 15 minutes, inoculated with spores, and allowed to ferment at 30° C on a shaker for 4 days.

A preliminary experiment was performed with actinomycete cultures 3644 and 8476 to determine if antibacterial substances produced in the artificial media were also produced in the soil cultures. The tests were made as described for the shaken cultures, applying the supernatant from the soil cultures to the filter paper disks. It was found that antibacterial activity was present in each culture where

an addition had been made to the clay. Culture 8476 was the more potent of the two, and this organism was therefore selected for further experiments.

TABLE 3.—*Inhibition of Azotobacter vinelandii heavily inoculated into various soil cultures of an antibacterial actinomycete (8476) and incubated 4 days at 30° C.*

Soil medium	Azotobacter cells per ml of inoculated soil suspension	
	Actinomycete present	Actinomycete absent
Clay soil	1×10^5	1.4×10^7
Clay soil + leaf mold	0	1.5×10^7
Clay soil + cow manure	0	1.6×10^7
Clay soil + sheep manure	0	1.8×10^7
Clay soil + fertilizer (4–8–5)	0	1.5×10^7
Clay soil + fertilizer (15–6–4)	0	1.4×10^7

A second series of the soil mixtures was then set up in four groups. Two sets were shaken and two were kept still. Of the two sets on the shaker, one was inoculated with spores of actinomycete 8476, the other kept sterile. In like manner, two sets of treatments were prepared for the still flasks. The sets to be shaken were incubated at 30° C on the shaker for 4 days, after which time all four sets were inoculated with 0.5 ml of a very turbid broth suspension of *Azotobacter*. All flasks were allowed to incubate at 30° C for 4 more days for the purpose of determining the survival of the bacteria in various soil mixtures with and without the antibiotic actinomycete. For the purpose of making survival tests of the *Azotobacter*, agar plates of a minimal medium were poured and allowed to cool. The composition of this medium, which we have designated as *Azotobacter* minimal solution, is as follows: K_2HPO_4, 0.8 gram; KH_2PO_4, 0.2 gram; $MgSO_4$, 0.2 gram; NaCl, 0.2 gram; $CaSO_4$, 0.1 gram; $Fe_2(SO_4)_3$, 0.01 gram; sucrose, 20.0 grams; trace elements solution, 0.5 ml; and water, 1,000 ml. One half ml of the trace elements solution provided the following amounts of essential elements in p.p.m.: B, 0.005; Mn, 0.01; Zn, 0.05; Cu, 0.005; Mo, 0.005. Difco agar was added in the amount of 15.0 grams per liter to make a gel. The pH of this medium was 7.0. One ml of the supernatant was taken from each flask, diluted 1/1,000, and pipetted onto the surface of an agar plate. These plates were incubated at 30° C for 48 hours, and then colony counts were made of the *Azotobacter*. The results obtained with the shaken soil cultures are given in Table 3. In the sterile soil treatments without any actinomycete, the calculated number of *Azotobacter* cells was approximately 1.5×10^7 per ml of soil suspension. In the series of treatments in which *Azotobacter* was incubated with the actinomycete present in the soil mixtures, marked reduction in the number or complete loss of viable cells was observed.

The results of the nonshaken cultures were comparable to those of the shaken series, but somewhat less striking. The number of viable *Azotobacter* cells was greatly reduced but not completely eliminated

by the actinomycete cultures. Possibly in the still soil cultures there was less thorough mixing and perhaps a lower concentration of the antibiotic substance present.

For the purpose of determining the possible production of antibiotic substances in cover crop types of materials, cultures of actinomycete 8476 were set up with leaf mold, macerated white clover plants, and winter rye leaves mixed with wet soil in Erlenmeyer flasks. The cultures were allowed to incubate at 30° C for 1 week; tests were made by transferring a portion of the fermented mate ial to the surface of *Azotobacter* agar pour plates. After 24 hours marked inhibition was indicated by the clear zones around the materials where the bacteria were unable to grow.

It should be mentioned here that additional evidence for the formation of antibacterial substances in soil was obtained with soil filtrates prepared by adding a small quantity of water to the soil cultures and filtering the supernatant through a Seitz filter. Sterilization of soil cultures of a number of different actinomycetes in some instances caused destruction of the antibacterial activity but in others the activity was retained. The activity of wet soil in which actinomycetes had grown for 1 week was tested also by direct application of small amounts of soil to *Azotobacter* pour plates. An example of the inhibition obtained in such experiments is illustrated in Fig. 1B.

GROWTH AND ANTIBACTERIAL ACTIVITY OF ACTINOMYCETE 8476 CULTIVATED ON DIFFERENT FORMS OF NITROGEN

In view of the observed activity of soil actinomycetes against *Azotobacter*, it was decided to make a study of the relative growth and production of antibacterial activity by a selected strain of actinomycete cultivated in a basal medium supplied with various forms of nitrogen. Strain 8476 which had been isolated from a corn field near Slaton, Tex. was chosen for this study because of its superior activity. The basal medium was the sucrose salts minimal *Azotobacter* solution which was described above.

Nitrogen was supplied in equivalent amounts at levels of 0.1, 1.0, and 8.0 grams per liter. The sources of nitrogen used were: $NaNO_2$, $NaNO_3$, $(NH_4)_2SO_4$, asparagine, Difco tryptone, and vitamin-free casein hydrolysate of General Biochemicals, Inc. The media were dispensed into 125-ml Erlenmeyer flasks, autoclaved, and then inoculated with a spore suspension of the actinomycete. After growing for 4 days at 30° C on a shaker, the fermented liquids were tested against *Azotobacter* with the paper disk method. Growth of the actinomycete was determined by filtering the mycelium and weighing the dried mats. The widths of inhibition zones at the edge of the paper and the dry weights of the actinomycete are given in Fig. 2. Only traces of growth were observed in the media supplied with inorganic sources of nitrogen in the form of $-NO_2$ and $-NO_3$, and this only at the lowest concentration. The best growth was found to occur in media containing relatively large amounts of tryptone or intermediate levels of casein, but the antibacterial activity was not correlated with the amount of growth in enriched solutions. Casein appeared to

be unfavorable for growth at the level of 8.0 gm. of N per liter. Although asparagine did not permit great growth at any of the levels employed, the largest of all inhibition zones were found with asparagine supplied at 8.0 gm. of N per liter. Control tests showed that this level of asparagine was not toxic to the bacteria. This experiment indicates that luxuriant growth of the antibacterial actinomycete is favored by a medium rich in the components of proteins, but that the elaboration of antibiotic substances does not necessarily depend upon very rapid or extensive vegetative development of the antagonist.

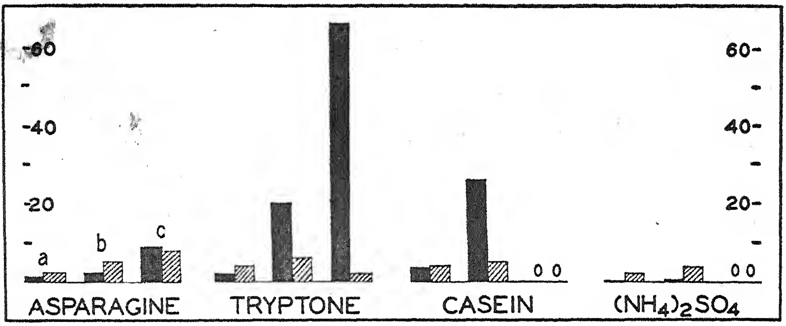

FIG. 2.—Growth and antibacterial activity of actinomycete 8476 cultivated in media containing different forms of nitrogen. Growth of the actinomycete in mgm dry weight (solid columns) varies with nitrogen supplied at levels of 0.1 (a), 1.0 (b), and 8.0 (c) grams per liter; inhibition zones of *Azotobacter* in mm at edge of filter paper disks is shown in hatched columns for each nitrogen level.

Tests were made to determine whether the action of actinomycete 8476 was bactericidal or whether the growth of *Azotobacter* was only temporarily depressed. Fermented asparagine medium was applied in glass cups to agar pour plates heavily seeded with *Azotobacter*. After 2 days, small portions of the agar containing the bacteria in a test plate were removed from the zone of inhibition and from regions where growth was abundant in the same plate. These agar pieces were inoculated into enriched nutrient broth. The results indicated that in this case the activity of the actinomycete was bactericidal, because no viable bacteria could be demonstrated in the zone of inhibition after 48 hours of exposure to the actinomycete products.

The results with extraction experiments which were performed on actinomycete-fermented soil and cover crop materials suggest that a number of different substances may be concerned. It appears that the activity of culture 8475 is not actinomycin because the material is not soluble in ether. Further chemical work on selected cultures is in progress.

DISCUSSION

The widespread occurrence of microorganisms which possess the potentiality of producing powerful antibiotic substances active against disease-producing bacteria and other organisms in soils has been recognized for a long time (2, 6). Research in this field, however,

has been directed primarily toward the possible utilization of antagonistic interrelationships among the component species of the soil microflora for the purpose of controlling or eradicating phytopathogenic bacteria and fungi. Among the large number of actinomycetes which have been studied, comparatively few exhibit antagonism against gram-negative bacteria. Nakhimovskaija (1) and many others have described the antagonistic effects of soil actinomycetes. From some soil actinomycetes, purified substances, such as the actinomycins A and B, actinomycetin, streptothricin, and actinomycin have been prepared (5). That both bacteriostatic and bactericidal substances are present in soils has been shown by the work of Waksman and Woodruff (4) with various extracts. On the basis of their observations these authors concluded that antagonistic substances of the actinomycin type may accumulate in soils, but that the action of these substances is probably diminished greatly by the humus compounds in soils. In another paper, Waksman and Woodruff (3) showed also that actinomycin A and B prevented the growth of *Azotobacter* in concentrations of 1:1,000,000, and inhibited nitrogen fixation by this organism in artificial culture media. The possibility that soil organisms may be distinctly injurious to beneficial bacteria, such as the free-living and symbiotic nitrogen fixers, has been but little investigated.

The simple experiments reported in this paper support the view that actinomycetes which are widely distributed in soils produce substances which inhibit the development of nitrogen-fixing bacteria. Although organic carbon is probably a limiting factor for growth of the antagonistic actinomycetes as well as for *Azotobacter* in many soils, it seems clear that nutritive conditions in soil need not be such as to provide for rapid and extensive growth in order to have antibiotic substances elaborated. It seems reasonable to suppose that the inhibition of *Azotobacter* obtained in experiments with actinomycetes grown in soils and in farm residues in the laboratory are indicative of conditions in the field. In the light of such experimental data, antibiosis must be considered on a broader basis than a special means by which plant and animal disease-producing bacteria and fungi may be held under control. The importance of microbial antagonism in theoretical forest and field ecology, and in practical agriculture as well, is emphasized by the data reported in this paper.

SUMMARY

The inhibition of *Azotobacter vinelandii* by 25 cultures of actinomycetes isolated from soil samples obtained in different parts of the world is demonstrated with nutrient agar streak plates and with shaken culture broths in filter paper agar plate tests. The nitrogen-fixing bacteria are either greatly reduced in number or completely killed by actinomycete cultures during incubation together in various mixtures of soil and fertilizers and crop residues. The data emphasize the importance of microbial antagonism as a factor to be considered in theoretical ecology as well as in practical agriculture.

LITERATURE CITED

1. NAKHIMOVSKAIJA, M. I. The antagonism between actinomycetes and soil bacteria. Microbiology, 6:131–157. 1937.
2. WAKSMAN, S. A., and WOODRUFF, H. B. The soil as a source of micro-organisms antagonistic to disease-producing bacteria. Jour. Bact., 40:581–600. 1940.
3. ————, ————. Actinomyces antibioticus, a new soil organism antagonistic to pathogenic and non-pathogenic bacteria. Jour. Bact., 42:231–249. 1941.
4. ————, ————. The occurence of bacteriostatic and bactericidal substances in soil. Soil Sci., 53:233–239. 1942.
5. ————, HORNING, E. S., WELSCH, M., and WOODRUFF, H. B., Distribution of antagonistic actinomycetes in nature. Soil Sci., 54:281–296. 1942.
6. ————. Microbial antagonisms and antibiotic substances. Commonwealth Fund, New York City. 1945.

Influence of 2,4-D Spray Applications on Vegetative Growth and Seed Development in Timothy[1]

Paul C. Marth, Vivian K. Toole, and Eben H. Toole[2]

MANY of the common lawn and pasture grasses, such as Kentucky bluegrass, redtop, fescue, ryegrass, and others, have proved to be quite resistant to 2,4-dichlorophenoxyacetic acid (2,4-D) when used as a differential herbicide to eradicate many of the weeds that infest such plantings. This report is concerned with preliminary experiments on the effects of spray applications of 2,4-D and related compounds on the vegetative growth of timothy. Data also were obtained on the germination of timothy seed that was produced on areas treated with 2,4-D, and on the relative effectiveness of these compounds in killing a number of serious farm weeds.

MATERIALS AND METHODS

For the purpose of the experiment, plots 4 feet wide and 25 feet long were used. Two parallel series of 16 plots each (total of 32 plots) were laid out on March 27, 1946, on a rather uneven established stand of timothy, *Phleum pratense*, that had become infested with the following weedy plants; Wild garlic, *Allium vineale;* broad-leaved plantain, *Plantago major;* narrow-leaved plantain, *Plantago lanceolata;* common winter cress, *Barbarea vulgaris;* early winter cress, *Barbarea verna;* bitter dock, *Rumex obtusifolium;* sheep sorrel, *Rumex acetosella;* common yarrow, *Achillea millifolium;* oxeye daisy, *Chrysanthemum leucanthemum;* and Indian strawberry, *Duchesnia indica.*

On the above date, when the timothy and weeds had developed from 2 to 6 inches of new vegetative growth, a single plot in each series received a spray application of 1,000 p.p.m. concentration of either 2,4-dichlorophenoxyacetic acid (2,4-D) or the ammonium salt, morpholine salt, triethanolamine salt, acetamide or amyl ester form of this acid. A similar plot in each series was sprayed with 2,000 p.p.m. concentration of each of these compounds. The various spray treatments were assigned at random in each series of plots and four unsprayed plots were left in each series. Carbowax 1,500 at 2.0% concentration was used as a dispersing and spreading agent for the acid, acetamide, and ester compounds, while in the case of the various salts, which are directly soluble in water, 0.5% Carbowax was used as a spreader. Each spray treatment was applied with a small mechanically operated pressure sprayer at the rate of 5 gallons per 1,000 square feet and 100 pounds pressure so as to apply approximately 1.5 and 3 pounds per acre of each herbicide at the 1,000 p.p.m. and 2.000 p.p.m. spray concentration, respectively.

Periodic observations were made on the effects of the spray treatments on the growth of both timothy and weeds from May 10 until July 26 when the timothy was harvested by plots. At harvest the timothy seed heads were starting to shatter and were removed with the attached straw to a greenhouse bench to dry. The seed was permitted to mature in the seed heads for a period of 45 to 54 days, after which it was rubbed out by hand and held for germination tests.

The seed[3] was cleaned, September 20, 1946, on an air blast blower designed by Leggatt (1).[4] In the samples having weed seeds it was necessary to remove them by sieving and hand picking.

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[1]Contribution from the Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication April 26, 1947.

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[3]"Seed" as used in this paper refers to the mature caryopsis with the enclosing lemma and palea when these are persistent.

[4]Figures in parenthesis refer to "Literature Cited", p. 783.

Germination tests were started September 24, 1946. As a period of 2 months had elapsed since the harvest of the seed and since the seed was dried in the straw, dormancy of the seed was not expected (4). The seed was germinated in petri dishes on blotting paper moistened with distilled water or with a 0.2% solution of potassium nitrate. The seed was placed at an alternating temperature of 20° to 30° C, with light at the higher temperature. The tests were held at the first-mentioned temperature for approximately 16 hours and at the second temperature for 8 hours. The temperatures of the chambers were maintained within ± 1° C. The 30° unit was a glass-enclosed chamber in a north window. Seed from each plot was germinated in quadruplicate. Only those seedlings having a normally developed root and shoot were considered as germinated.

RESULTS

EFFECT OF SPRAY APPLICATIONS ON THE VEGETATIVE GROWTH OF TIMOTHY

Within a week following application of the sprays the foliage of timothy in all the sprayed plots was slightly more yellow in color than that in the unsprayed plots. After 2 weeks the timothy in plots that received 2,000 p.p.m. spray concentration of the several compounds (3 pounds per acre) was checked in growth and quite yellow and sickly in appearance, with the exception of those plots that received the acetamide form of 2,4-D at this spray concentration. The timothy receiving this spray treatment was but slightly affected. At this time timothy in plots that received 1,000 p.p.m. spray of each of the different chemicals appeared to be recovering from the initial foliage-yellowing effects.

On May 10, 44 days after treatment, the timothy appeared to have fully recovered from the initial depressing effects and was green and growing rapidly. This response was noted even in those plots that had previously shown considerable growth retardation and yellowing of timothy.

At harvest, July 26, 1946, there appeared to be no consistent differences between the various plots with regard to the growth of timothy. Certain plots that originally had been checked in growth by the sprays but in which almost all weeds were killed by the chemicals, appeared to have produced a greater abundance of timothy seed heads than adjacent weedy control plots. However, it was felt that reliable data on the effects of the various chemicals on the yield of timothy seed could not be obtained in this experiment because of the high variability in stand of both timothy and of weeds that existed among the different plots.

GERMINATION OF TIMOTHY SEED PRODUCED ON VARIOUS SPRAYED PLOTS

On the basis of a preliminary count, made after 6 days, of normal seedlings having the plumule elongated ¼ inch or longer, no differences in germination were found as a result of the different hormone treatments. There was a highly significant difference between the seeds moistened with water and those moistened with a dilute solution of potassium nitrate at this preliminary count, the latter group showing greater germination. An analysis of the data of the preliminary count of seeds, germinated with water only, shows no difference

in germination of the seed from the different treatments, thus indicating no influence of hormone treatment on dormancy. At the final count, after 10 days, the seed germination tests moistened with potassium nitrate were again significantly better than those with water, but there were no differences among the various hormone treatments (Table 1). This stimulation with potassium nitrate indicates some dormancy in the seed.

TABLE 1.—*Percentage of germination of timothy seed from plots sprayed with various forms of 2,4-dichlorophenoxyacetic acid at two concentrations.**

Spray material	Plots receiving 1000 p.p.m.		Plots receiving 2000 p.p.m.	
	Germinated with KNO_3, %	Germinated with H_2O, %	Germinated with KNO_3, %	Germinated with H_2O, %
2,4-D acid	97	97	97	96
2,4-D amide	99	96	99	95
Ammonium salt of 2,4-D	99	94	99	97
Amylester of 2,4-D	98	97	99	97
Triethanolamine salt of 2,4-D	99	98	99	98
Morpholine salt of 2,4-D	98	95	99	98
Controls, not sprayed	98	95		

*Average of two plots each per spray treatment and eight plots each for the controls, with tests of 4 × 100 seeds from each plot.

EFFECT OF THE SPRAYS ON CERTAIN WEEDS

The varied weed infestion of this field of timothy gave an opportunity to study the differential effects of an early spring application of different forms of 2,4-D on the several kinds of weeds.

Wild garlic was most severely affected by the acid sprays. A few plants sprayed with the lower concentration of the acid recovered but produced no aerial bulblets. The ammonium and triethanolamine salts at 2,000 p.p.m. had a drastic effect on the garlic but were only mildly effective at 1,000 p.p.m. The other forms of 2,4-D used severely checked the growth of garlic so that few stalks were produced, but many of the plants retained some green color. Broad-leaved plantain was almost completely killed by all compounds at 2,000 p.p.m., but at 1,000 p.p.m. the acid was definitely superior to the salts. Bitter dock appeared to be sensitive to all sprays used, although the distribution of this weed was too uneven for comparison of the effect of the various compounds. Older plants showed some recovery in early summer. With this spring application sheep sorrel showed about 75% killing of the top growth at 2,000 p.p.m. spray concentration, but recovery tended to be rapid. Narrow-leaved plantain, cress, and Indian Strawberry were killed by all treatments. Satisfactory killing of common yarrow and oxeye daisy was not obtained with any of these compounds at 1,000 p.p.m. However, at 2,000 p.p.m. the acid and salt forms killed approximately 99% of the plants, while the acetamide and amyl ester forms killed 85 to 90%.

DISCUSSION AND CONCLUSIONS

The vegetative growth reponse of timothy following spray applications of 2,4–D and related compounds was found to be somewhat different from that of certain other grasses. Established plants of Kentucky bluegrass, fescue, redtop, and ryegrass, for instance, have shown a reduced rate of growth immediately following 2,4–D spray applications (3), but the foliage of these grasses often became temporarily darker green in coloration than the controls. In lawn treatments this response to the chemical is not objectionable. Timothy, in the present experiments, not only was depressed in growth, but the foliage developed a rather pale yellow, sickly appearance, although it appeared to have fully recovered after 44 days. In this respect timothy behaved somewhat the same as bluegrass and differed from the very sensitive grasses, such as the bents, which may be permanently damaged or may require several months to recover from 1,000 p.p.m. spray concentration of 2,4–D.

It is of interest to note that, although the timothy showed injurious effects of the chemicals early in the season, the seed stalks and seed heads that developed seemed unaffected. Likewise, the seeds that developed on all the various treated plots germinated equally well.

In evaluating the weed-killing effects of the various forms of 2,4–D that were used, it should be borne in mind that the sprays were applied rather early in the growing season. At this season the translocation of materials in the stems may have been primarily from the roots to the tops and with a minimum of translocation of the 2,4–D downward so as to affected the root system (2). This factor may have been of particular importance with such weeds as dock, yarrow, and others that have underground storage organs from which new tops may regenerate if these organs do not receive sufficient 2,4–D stimulus to destroy them.

LITERATURE CITED

1. LEGGATT, C. W. A new seed blower. Proc. Off. Seed Analysts, 1938: 120–132. 1939.
2. MITCHELL, J. W., and BROWN, J. W. Movement of 2,4–D stimulus and its relation to the translocation of organic food materials in plants. Bot. Gaz., 107: 393–407. 1946.
3. ——————, and MARTH, P. C. Effects of 2,4–D on the growth of grass plants. Bot. Gaz., 107:276–284. 1945.
4. TOOLE, EBEN H. Observations on the germination of freshly harvested timothy seed. Proc. Int. Seed Testing Assoc., 2:119–139. 1939.

An Allele for Recessive Red Glume Color in Sorghum[1]

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MANY sorghum varieties have either red or black glumes and corresponding reddish or blackish plant discolorations. There are variations in intensity, shade, and distribution of the colors caused by environmental and morphological and genetical modifications (1)[3]. The contrasting glume colors with the more stable modifications are useful in describing varieties, such as "intense dark red" or "black with apices of outer glumes uniformly straw-colored to reddish brown" (9, pages 70,77).

The red plant color has been reported as a single-factor dominant to black (8); the factor pair has been designated *Qq* (2); and these genes have been found linked with those for brown subcoat [nucellar layer (6)], *Bb*, and green-striped plants, *Gs gs*, (7). Conversely, black glumes have been reported dominant to red (5), and Laubscher (4) found the crossover percentage with brown subcoat comparable to that previously obtained when red glumes were dominant to black. He suggested an allelomorphic series at the locus for glume color. Data tabulated at the Chillicothe, Texas, station bear on this suggestion.

MATERIALS

Part of the crosses described here were made specifically to determine crossover percentages between factors for glumes, subcoat, and green-striped. Others were made for other purposes, but the segregations for the above characters also were included in the tabulations. Since the tables showing detailed segregations in each of the individual populations are entirely too voluminous for a short paper, only the totals for individual years are shown. Varieties used as parents in the various crosses are listed below. In addition, several genetic stocks that carried the factors for green-striped and male sterile were used as parents, but the genes for glume color in these stocks were derived directly or indirectly from the named varieties or from closely related strains of Blackhull kafir and feterita.

Dominant red (*QQ*)	Black (*qq*)
Chusan Brown kaoliang (S.P.I. 23231[4])	Texas Blackhull kafir (F.C. 8962)
Red kaoliang (F.P.I. 62428)	Dwarf feterita (C.I. 810)
Brown kaoliang (F.P.I. 66384)	Freed (S.P.I. 29166)
Brown kaoliang (F.P.I. 82336)	Chiltex (F.C. 8917)
Dwarf Java (S.P.I. 39269)	Ajax (F.C. 6620)
Acme broomcorn (C.I. 243)	Chinese (black) amber sorgo (F.C. 8728)
Honey sorgo (F.C. 6605)	

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station at Texas Substation No. 12, Chillicothe, Tex. Technical Series, Texas Agricultural Experiment Station. Received for publication April 28, 1947.

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[3]Figures in parenthesis refer to "Literature Cited," p. 790.

[4]S.P.I. and F.P.I. denote accession numbers of the Division of Plant Exploration and Introduction; F.C. denotes accession number of the Division of Forage Crops and Diseases, and C. I. accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture.

Recessive red (q^rq^r)

Pink kafir (F.C. 13642)	Red amber sorgo (S.P.I. 17548)
Red kafir (F.C. 6608)	Maizo amber sorgo (F.C. 16153)
Colman sorgo (F.C. 13350)	Denton sorgo (F.C. 9546)
Kansas Orange sorgo (F.C. 9108)	Leoti sorgo (F.C. 6610)
Straightneck sorgo (F.C. 13490)	Shallu (Agros. 2650)

RESULTS

Summaries of F_2 populations in which red glumes were dominant to black (Qq) and in which presence and absence of subcoat (Bb) was segregating in the coupling phase with glume color are shown in Table 1. The crossover percentage of all F_2 populations is 16. The crossover percentage in a small backcrossed population is 21. The difference divided by the standard error of the difference, or t, is 1.724 and not significant, and the weighted average crossover percentage of the F_2 and backcrossed populations is 16 ± 0.4.

In a like manner, populations segregating for black and recessive red glumes (qq^r) and for subcoat are shown in coupling and repulsion phases. The crossover percentages are 17 and 18, respectively, and the difference is not significant; the weighted average of both phases is 17 ± 0.8. Crossover percentages between factors for subcoat and for glume color when red is dominant to black and when red is recessive to black are not significantly different and have a weighted average of 16 ± 0.4.

Similar summaries of populations segregating for glume color and for green-striped plants are given in Table 2. The difference of 2 in crossover percentage when red glumes were dominant and when they were recessive is not significant. The weighted average is $26\pm0.9\%$.

A number of back crosses involving the factors for glume color and green-striped were made in 1940 using male sterile stocks as the female parent. Most of the seed was planted in 1941, but chinch bugs destroyed the planting. The remnant seed was planted in 1942, but a considerable portion of the green-striped plants failed to survive. The segregations are shown in Table 3. The recombination percentages are not significantly different regardless of gene associations going into the crosses, and the average of 26% is the same as that found in the F_2 populations.

F_2 populations of dominant red crossed with recessive red have been grown, but the tabulations are not shown. Three such populations grown in 1946 segregated for subcoat with 24.4% recessive, but all of the 419 plants were red. Other populations grown in 1936, 1942, and 1944 estimated to have exceeded 2,000 plants were examined and in no case was a black-glumed plant found.

DISCUSSION

The simplest explanation of the association of dominant red, black, and recessive red glumes with subcoat and green-striped is an allelomorphic series at the glume color locus, as suggested by Laubscher, and it is proposed that the gene for recessive red be designated q^r.

TABLE 1.—*Segregation of dominant red (Q), black (q), and recessive red (q^r) glumes with subcoat (Bb).**

Year grown	Factors Xx	Phase	Total population	Number of plants				Percentage recessive		Crossover %	Difference/ S.E. of Dif.
				X-		xx					
				B-	bb	B-	bb	xx	bb		
1946	Qq	CS	1,262	876	96	97	193	23.0	22.9	17±1.2	
1944	Qq	CS	281	184	17	24	56	28.5	26.0	15±2.3	
1939	Qq	CS	283	193	19	25	46	25.1	23.0	17±2.5	
1936	Qq	CS	8,922	6,167	656	649	1,450	23.5	23.6	16±0.4	
Total.......	Qq	CS	10,748	7,420	788	795	1,745	23.6	23.6	16±0.4	
1944	Qq	CB	198	77	16	26	79	53.0	48.0	21±2.9	
Weighted av. and Dif./S.E.D, CS and CB										16±0.4	1.724
1946	qq^r	CS	1,544	1,059	118	114	253	23.8	24.0	17±1.1	
1944	qq^r	CS	657	439	55	58	105	24.8	24.4	19±1.7	
Total.......	qq^r	CS	2,201	1,498	173	172	358	24.1	24.1	17±0.9	
1946	qq^r	RS	237	117	57	62	1	26.6	24.5	13±6.4	
1944	qq^r	RS	208	101	54	47	6	25.5	28.8	31±6.2	
1938	qq^r	RS	377	191	96	88	2	23.9	26.0	15±5.0	
1936	qq^r	RS	180	93	45	42	0	23.3	25.0	15±7.2‡	
1945†	qq^r	RS	556	283	133	136	4	25.2	24.6	17±4.1	
Total.......			1,558	785	385	375	13	24.9	25.5	18±2.4	
Weighted av. and Dif./S.E.D, CS and RS										17±0.8	0.385
Weighted av. and Dif./S.E.D, Qq and qq^r										16±0.4	1.111

*All crossover percentages and standard errors obtained from tables provided by Immer and Henderson (3) and weighted averages calculated by method shown in same paper.
†Laubscher (4).
‡Assuming one phenotype in double-recessive class.

TABLE 2.—*Segregation of dominant red (Q), black (q), and recessive red (q^r) glumes with green-striped (Gs gs).*

Year grown	*Xx*	Phase	Total population	Number of plants				Percentage		Crossover, %	Difference/ S.E. of Dif.
				X-		*xx*					
				Gs-	*gsgs*	*Gs-*	*gsgs*	*xx*	*gsgs*		
1946	*Qq*	CS	908	592	112	92	112	22.5	24.7	27±1.8	
1936	*Qq*	CS	1,960	1,271	199	213	277	25.0	24.3	24±1.1	
Total.......	*Qq*	CS	2,868	1,863	311	305	389	24.2	24.4	25±1.0	
1946	qq^r	CS	429	282	49	41	57	22.8	24.7	24±2.4	
1944	qq^r	CS	207	124	26	30	27	27.5	25.6	31±4.0	
Total.......	qq^r	CS	636	406	75	71	84	24.4	25.0	27±2.1	
1946	qq^r	RS	305	154	69	75	7	26.9	24.9	29±5.2	
1944	qq^r	RS	277	141	62	67	7	26.7	24.9	31±5.4	
1941	qq^r	RS	402	214	77	105	6	27.6	20.6	26±4.6	
Total.......	qq^r	RS	984	509	208	247	20	27.1	23.2	28±2.9	
Weighted av. and Dif./S.E.$_D$ CS and RS										27±1.7	0.287
Weighted av. and Dif./S.E.$_D$ *Qq* and qq^r										26±0.9	1.000

TABLE 3.—*Backcrossed populations segregating for glume colors and green-striped.**

Gametes		Number of plants					Percentage recessive		Cross-over %
			Red		Black				
♀	F_1	Total	*Gs-*	*gs gs*	*Gs-*	*gs gs*	Black	*gs gs*	
$q\ gs$	$\frac{q^r\ gs}{Q\ +}$	104	58	9	16	21	35.6	28.8	24 ± 4.2
$q^r\ gs$	$\frac{q\ gs}{Q\ +}$	42	17	4	10	11	50.0	35.7	33 ± 7.3
$q\ gs$	$\frac{q\ gs}{Q\ +}$	74	50	1	18	5	31.1	8.1	26 ± 5.1
			Black		Red		Red		
$q^r\ gs$	$\frac{q^r\ gs}{q\ +}$	19	7	2	2	8	52.6	52.6	21 ± 9.3
Total		239	132	16	46	45			26 ± 2.8

*Emergence of green-striped plants approximately 50% of total but survival rate lower than green in 1942.

While phenotypes of the Q and q^r genes could not be separated in any of the populations examined, it is possible that they would be slightly different if segregating in populations homozygous for all other factors. It is also possible, of course, that certain of the modifications of red and black represent other alleles which could be detected in suitable material.

Glume and plant color have been used interchangeably in this paper, but actually the glumes of Freed, Shallu, and Pink kafir are usually straw-colored although the varieties carry the factors for black, recessive red, and recessive red, respectively. They were used as parents in a number of crosses in an attempt to determine the inheritance of straw glumes. This character is of considerable importance in sorghum breeding. For instance, sudan grass seed producers spent years selecting for cream-hulled types, some with reasonable and some with moderate or little success. On the other hand, one of the major difficulties encountered by Karper and Quinby in developing Sweet sudan was the elimination of straw-glumed types. Freed and Shallu are two of the most consistently straw-glumed varieties, but usually color shows slightly at the bases of at least part of the glumes, often only inside, if conditions are favorable preceding maturity. And in one particularly favorable season, the glumes of Freed were fairly black with streaks of straw and those of Shallu uniformly light sienna rather than red because the variety is homozygous for brown (*pp*) plant color. A recessive dilution factor and a dominant glume color inhibitor have been reported (1), and there is some evidence that one

factor for straw glumes may be located on this same *q b gs* chromosome. Most of the populations grown at Chillicothe whether backcrosses, F_2, or F_3 generations have yielded little information. Undoubtedly, the influence of environment is one of the principle obstacles in studying the inheritance of straw glumes, for types with fully colored glumes, such as Blackhull kafir and feterita, have straw glumes when the plants mature under extremely hot and dry conditions, and such conditions nearly always occur at some time during the summer.

It may be of interest to note that all of the dominant red-glumed varieties used as parents in these crosses are of Asiatic origin except Acme broomcorn and Honey sorgo. The origin of the broomcorns is said not to have been determined (10). Honey is supposed to have descended directly from one of Wray's importations from Africa (9). The black-glumed parents presumably are all descended from African introductions, except Chinese amber which came from coastal regions in China and could have been a relatively recent introduction there or a hybrid form arising from an introduction. All of the recessive red-glumed varieties used are probably of African origin, directly or indirectly, except Shallu which was introduced from India and perhaps Leoti the origin of which is unknown but could have followed hybridization with Shallu. While these varieties were selected—but not for origin—and represent only an infinitesimal sample of the thousands of varieties and strains in the world, their color genes conform to the observation made several times that the Asiatic sorghums are preponderantly red-glumed, while the African forms are of both colors but include most of the blacks. If the recessive red forms occasionally arise as mutations from black rather than from dominant red, their distribution would be expected to parallel roughly that of the blacks. Whether the African red forms are preponderantly recessive red is not known, but in this small sample they were.

Vinall and Cron (8) reported the red glume color of Red amber sorgo dominant to black glume color and obtained a 3:1 ratio in the F_2. The accession numbers of the crosses were given as F. C. 8882 and 8883. In the card index of the Division of Forage Crops and Diseases, the female parent of F. C. 8882 is given as Red amber F. C. 6585. This strain is not grown at Chillicothe now and the cross could not be repeated. However, the card for F. C. 6585 reads: "Selected from C.I. 435...This selection resembles the Red Amber in color of the glume, but the head is somewhat more appressed. A heavy seeding type. Head selection made for the purpose of unifying the strain. H.N.V." And the accession card for C. I. 435 reads: "Amber? sorgo, 'Davis' from Missouri, Kansas City, Mo. 3/4/11. Through Seed Laboratory for identification. re: possible broomcorn." Apparently Vinall selected a type from heterogeneous material which he recognized as somewhat different from ordinary Red amber. This stock had been regarded earlier as possibly broomcorn which suggests the probability that hybridization or mixture and hybridization with broomcorn had occurred and plausibly accounts for the dominant red glumes in the selected strain of a variety that from other sources had recessive red glumes.

SUMMARY

Among plant colors in sorghum the genes for dominant red and recessive black have been designated *Qq* and have been reported linked with those for subcoat, *Bb*, and green-striped, *Gs gs*. A red which is recessive to black was found to have the same association with subcoat and green-striped and it is suggested that the allele be designated q^r.

The dominant red-glumed varieties used in the crosses were largely of Asiatic origin, while the black and recessive red-glumed varieties were largely of African origin.

The contradictory results in which Vinall and Cron reported the red glumes of Red amber sorgo dominant to black glumes whereas they were found to be recessive to black in these segregating populations are explained on the assumption that the strain used by Vinall and Cron had been selected from a broomcorn hybrid.

LITERATURE CITED

1. AYYANGAR, G. N. R., and PONNAIYA, B. W. X. Two new genes conditioning the tint of the colour on the glumes of sorghum. Current Sci. (India), 10:410–411. 1941.
2. ——————, VIJIARAGHAVAN, C., PILLAI, V. G., and AYYAR, M.A.S. Inheritance of characters in sorghum—the great millet. II. Purple pigmentation on leaf-sheath and glume. Indian Jour. Agr. Sci., 3:589–594. 1933.
3. IMMER, F. R., and HENDERSON, M. T. Linkage studies in barley. Genetics, 28:419–440. 1943.
4. LAUBSCHER, F. X. A genetic study of sorghum relationships. Union of So. Afr., Dept. Agr. and Forestry Sci. Bul. 242. 1945.
5. MARTIN, J. H. Sorghum improvement. U. S. D. A. Yearbook, 1936: 523–560. 1936.
6. STEPHENS, J. C. A second factor for subcoat in sorghum seed. Jour. Amer. Soc. Agron., 38:340–342. 1946.
7. ——————, and QUINBY, J. R. Linkage of the Q B Gs group in sorghum. Jour. Agr. Res., 57:747–757. 1938.
8. VINALL, H. N., and CRON, A. B. Improvement of sorghums by hybridization. Jour. Hered., 12:435–[443]. 1921.
9. ——————, STEPHENS, J. C., and MARTIN, J. H. Indentification, History, and distribution of common sorghum varieties. U. S. D. A. Tech. Bul. 506. 1936.
10. WASHBURN, R. S., and MARTIN, J. H. An economic study of broomcorn production. U. S. D. A. Tech. Bul. 347. 1933.

Early Generation Testing in Soybeans[1]

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The term "Early Generation Testing" has been used by maize breeders to include the several breeding procedures permitting the evaluation of germplasm of individual plants during the early stages of inbreeding. Furthermore, the "testing" usually includes testing in replicated trials rather than evaluating the phenotype of individual plants. The term is similarly used herein.

Although the use of topcross and other tester crosses for gamete evaluation is generally denied the breeder of naturally self-pollinated crops because of difficulties in making large numbers of crosses, an early, accurate appraisal of the germplasm of individual segregates in hybrid populations is of considerable advantage. Precise evaluation during early segregating generations permits the rapid elimination of inferior segregates and thereby enhances the probabilities of obtaining desirable combinations by raising the frequency of desired characters in the remaining population. It also expedites the final results, namely, release of a variety or varieties by allowing testing of the progenitors of prospective varieties on a regional basis before homozygosis has been entirely attained.

Elimination of entire crosses on the basis of yield tests of bulk populations of crosses has been suggested as one means of early generation testing in self-pollinated crops. Harlan, *et al.* (1)[3] studied the yield of all possible crosses among 27 varieties of barley and found combining ability of varieties could not always be judged by the performance of the varieties *per se*. Yields of unselected bulk crosses obtained from unreplicated 10-foot rows in F_2 to F_7 "were a sound indication of the crosses from which high-yielding segregates might be expected."

Harrington (3) found that heterosis as measured in bulk F_2 replicated yield trials of six wheat crosses indicated yield potentialities of segregates from these crosses. Bulk F_3 yield trials were considered of supplementary value. Varietal differences in contribution of yield potency to crosses were apparent. In one wheat cross Harrington (2) found that classification of several hundred single F_2 plants correctly predicted the value of the cross as to earliness, height, stem rust reaction, and seed characters. The F_2 yield results were somewhat misleading. In replicated yield studies of bulk populations of six crosses in barley, Immer (4) found substantial differences among

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[3]Figures in parenthesis refer to "Literature Cited", p. 811.

crosses consistent in F_2, F_3, and F_4 bulk generation tests. Differences among crosses as measured with spaced F_1 plants were not consistent with the solid-row, advanced generation tests. Lack of agreement was attributed to interaction of crosses × method of planting, which was particularly noticeable when the generations were grown in different years. Crosses involving certain parents were consistently low in the bulk yield tests.

Evaluation of segregates within crosses of self-pollinated plants generally has been made on an individual plant basis. A comparison by Immer (5) of the yield distribution of F_2 and parental single plants in three barley crosses revealed that the yield of an F_2 spaced plant was determined very largely by environmental factors. Low correlations generally found between the yield of single cereal plants in segregating populations and the mean of their progeny rows was attributed to this excessive environmental effect when plants were spaced. Harrington (2) concluded that actual yields of a given F_2 plant "tells very little respecting the inherited yielding ability of that plant."

The studies reported in this paper constitute an attempt to obtain fundamental information on soybean breeding methods during the progress of a practical plant breeding program. Answers to the following questions were sought: (A) Is heterosis as measured by yields of spaced plants in the F_1 generation indicative of the recombination potentialities of a cross? (B) Can one justifiably discard entire populations of crosses on the basis of their performance in spaced F_2 population or bulk population trials in the early segregating generations? (C) How effective is selection on the basis of performance of spaced F_2 plants? (D) How effective are replicated plant-progeny tests as a method of making selection within crosses as early as the F_3 and F_4 generations?

EXPERIMENTAL METHODS

Seventeen crosses between nine soybean varieties were used as a basis for this study. All parents were commercially grown varieties except Linman 533, an early selection from Manchu made by Dr. E. W. Lindstrom. To simplify pedigree designation, varieties were assigned single digit numbers as indicated below:

No.	Variety	No.	Variety
1	Dunfield	6	B. H. Manchu
2	Mandell	7	Mandarin
3	Illini	8	Linman 533
4	Mukden	9	Wisconsin Manchu 3
5	Richland		

The following crosses were studied:

Cross	Pedigree designation	Cross	Pedigree designation
Dunfield × Richland	15	Mukden × Richland	45
Dunfield × Linman 533	18	Mukden × B. H. Manchu	46
Mandell × Linman 533	28	Mukden × Mandarin	47
Illini × Dunfield	31	Richland × Mandell	52
Illini × Richland	35	Richland × B. H. Manchu	56
Illini × Mandarin	37	Richland × Linman 533	58
Illini × Linman 533	38	Richland × Wisc. Manchu 3	59
Mukden × Dunfield	41	B. H. Manchu × Dunfield	61
Mukden × Illini	43		

F_1 plants were grown in 1939 in spaced plantings in the field. The F_2 populations were planted with an 8-inch spacing between seeds and grown with the parents in a randomized block design with six replications. The plot consisted of a single row 60 spaces (40 feet) in length. All competitive plants (an adjacent plant on either side in the row) were harvested after maturity date and degree of lodging were ascertained. Plants were threshed individually and seed yield was obtained. Numbers of competitive F_2 plants harvested per cross varied from 129 to 165.

Degree of lodging in this and succeeding tests was determined objectively by assigning a lodging score to the plant or plants. A scale of scores was employed ranging from 1 (perfectly erect) to 5 (prostrate). Maturity was recorded as the number of days from September 1 until all pods had ripened.

An F_3 test consisting of progenies of 41 F_2 plants in each cross was grown with the nine parents in a cubic lattice design with three replications in 1941. Some selection for yield was necessary in that only those F_2 plants were used which had adequate seed to plant three plots. Approximately the lower third of the F_2 populations, therefore, was not sampled. Each plot consisted of two randomly occuring 8-foot rows 32 inches apart, one of which was planted at a normal rate, the other space planted with 8-inch intervals. Height, lodging, maturity, and seed yield were determined on the solid planted subplot and only yield on the space-planted subplot. Four plants in each space-planted row were selected and threshed separately, their weight later being added to that of the remainder of the subplot.

On the basis of desired maturity, lodging resistance, adequate height, and high yield, progenies of 251 F_2 plants, regardless of the cross from which they were derived, were selected as warranting further testing. One F_3 plant of the 12 individually threshed plants from each of the progenies of the 251 F_2 plants was selected for planting in the F_4 test in 1942. To provide a measure of differences between sister F_3 selections in the F_4 generation, a second F_3 plant was selected from the 51 progenies judged as superior in agronomic characters. Selection among the 12 F_3 plants consisted of choosing plants which had adequate seed to plant three plots. The F_3 progenies were grown with their parents in a triple lattice design with plot and subplot features identical with the test of the previous year.

Using high oil content as an additional criterion for selection, a total of 127 rigidly selected F_4 lines were saved for testing in the F_5 generation in 1943. Progenies of one F_4 plant of each of these lines and a second F_4 plant in 51 of the lines were tested in 1943 with parents in a triple lattice design containing three replications. Individual plants were again selected to propagate each line.

After further elimination of inferior lines on the basis of the F_5 test in 1943, the surviving lines were divided into two groups (early and late) on the basis of maturity. Plant selections were then bulked and normal variety testing procedures were employed in subsequent years.

Concurrent with the above pedigree test, all crosses were advanced in bulk. Individual seed yields were obtained on five greenhouse-grown F_1 plants per cross during the winter of 1941–42. The F_1 plants and parents were grown in a gravel bench sub-irrigated with nutrient solution, and arranged in a randomized block design containing five replications. During 1942 additional F_1 plants were grown in the field with the parent plants directly opposite in adjacent rows. Yields were determined only on those sets of plants in which all three were competitive. Bulk, unselected F_2 to F_5 populations of each cross were tested, together with the parents in six replicates in 1943. Generations and parents of each cross comprised the subplots of a split-plot design. Additional bulk population tests included a bulk F_3 test in 1941 with three replications and a bulk F_4 test in 1942 at three locations in northern Iowa, namely, Hudson, Kanawha, and Cherokee. With this exception, all experimental data were obtained at Ames.

EXPERIMENTAL RESULTS

INTERCROSS STUDIES

Heterosis in F_1.—To determine to what degree heterosis exhibited by F_1 crosses was indicative of the yield of segregates obtained, a limited F_1 spaced-plant yield test was conducted in the greenhouse and a more

extensive test in the field. Yield of seed of F_1 plants and increase over parents appear in Table 1. All crosses, when grown in the field, and all but one when grown in the greenhouse, yielded above the mean of the highest parent.

TABLE 1.—*Heterosis of spaced F_1 plants as evidenced by seed yield.*

Cross	Greenhouse			Field			
	F_1 mean yield per plant, grams†	Increase over mean of parents, %	Increase over high parent, %	No. F_1 plants	F_1 mean yield per plant, grams	Increase over mean of parents, %	Increase over high parent, %
15	6.4	59.2**	46.8**	38	74.9	26.7**	24.2**
18	5.3	35.4**	21.1	39	71.0	15.4*	11.6
28	4.6	21.7	11.7	44	69.6	23.6**	20.2**
31	5.4	28.6*	23.9	48	66.6	19.4**	16.4*
35	6.9	79.3**	71.3**	54	76.9	13.9**	5.9
37	4.6	28.9*	13.9	36	84.4	43.3**	20.7**
38	6.2	66.8**	54.5**	46	89.1	28.8**	18.5**
41	5.1	−1.2	−14.2	35	85.4	26.5**	23.2**
43	7.3	46.2**	23.0*	65	74.6	9.1*	7.3
45	7.7	60.0**	29.7**	42	71.9	11.0*	6.2
46	6.7	50.7**	13.5	28	83.6	21.2**	15.6
47	7.6	68.5**	28.4**	46	77.4	37.7**	14.0**
52	6.1	56.9**	48.5**	34	70.9	11.3*	6.6
56	5.6	68.9**	53.3**	54	70.0	16.7**	14.0**
58	4.5	27.5*	23.4	58	70.3	14.5**	7.2
59	5.7	56.8**	56.0**	50	75.8	39.3**	38.6**
61	6.2	69.6**	43.1**	33	68.4	8.1	7.4
$\bar{x}$	5.99	48.5**	32.2**	750	74.99	20.8**	14.5**

*F_1 yield exceeds mean yield of parents or high parent significantly at the 5% level of probability.
**F_1 yield exceeds mean yield of parents or high parent significantly at the 1% level of probability.
†Means of five F_1 plants for each cross.

Differences between crosses in the degree of heterosis were in distinct disagreement in the two tests, e.g., cross 35 showed the greatest increase in yield over the higher yielding parent in the greenhouse but the least in the field. Differences in conditions under which the two tests were conducted probably contributed to the differences of heterotic expression. Comparison of the F_1 mean yields in the greenhouse is valid, least significant differences between crosses for the 5% and 1% probability levels being 1.2 and 1.6 grams per plant, respectively. Differences among F_1 mean yields in the field cannot be tested for significance as the crosses and parents were grown in adjacent but unreplicated plots. Determination of significance of F_1 over parents within each cross, however, is possible because each F_1 plant was grown between its parents.

When the degree of heterosis as expressed in the F_1 (Table 1), is compared with the mean yield of F_5 selections (Table 2, column 15), which were retained on the basis of general agronomic desirability, no relationship among the crosses is apparent. This might be illustrated with cross 45 which was second poorest among the crosses as to

heterotic expression over the higher yielding parent in the field, yet it yielded a number of desirable F_5 lines. Comparison of heterosis in F_1 with means of bulk crosses, also Table 2, shows no significant correlation with any generation in any year tested. In this experiment it would seem that degree of heterosis of F_1 plants could not be used as a reliable criterion to predict the yield potentialities of segregates from a cross.

Date of maturity, plant height in inches, and lodging scores of F_1 plants gave no inter-cross information of value. Means of these variates and seed yield in grams per plant for the 17 crosses were as follows:

	Maturity	Height	Lodging		Yield
Early, short, erect parent	21.4	34.7	2.62	High parent	65.48
Late, tall, lodged parent	32.8	42.5	3.82	Low parent	58.69
F_1	27.2	41.6	2.97	F_1	74.99

Date of maturity in the F_1 was intermediate between that of parents, and tallness and lodging resistance showed partial dominance. These relationships were consistent in the 17 crosses studied. As previously noted in Table 1, seed yield of the high parent was exceeded by that of the F_1.

Spaced F_2 population trial.—In the pedigree selection portion of this breeding study, the F_2 generation was space-planted in a replicated design and individual plant data were obtained on competitive plants for yield, maturity, and lodging. Mean performance of the 17 crosses for the above three variates appears in the third from the right column in Tables 2, 3, and 4, respectively. To determine the effectiveness of these data as a means of evaluating the crosses, a comparison can be made with the righthand column of the corresponding tables in which is found the mean performance of F_5 lines derived from the crosses. To facilitate this comparison the correlations between the two sets of means have been entered at the bottom of the F_2 colums.

It will be noted that a significant correlation exists between the two sets of means in each of the three variates. This indicates that the means of the characters measured on the F_2 plants of a cross were fairly effective in predicting the performance of subsequent selections from that cross. Lodging susceptibility scores of the spaced F_2 plants were perceptibly lower than those of the F_5 lines which were tested at normal rates of planting. This difference is thought to be primarily attributable to differences in growth habits at the two planting rates rather than seasonal differences. When space planted, soybean plants have a tendency to grow very sturdy, branch profusely, and lodge less than when planted at normal rates. The long lateral branches, however, are readily broken down by winds. Accuracy of lodging determinations is thereby minimized and variance of individual plant yields is undoubtedly increased.

Bulk population trials.—In certain other self-pollinated species bulk population yield trials have proved of some value in predicting the yielding potentialities of subsequent selections from a cross,

TABLE 2.—*Mean yield in bushels per acre of 17 crosses in soybeans.*

Cross	F_2 to F_5 bulk population test, Ames, 1943								F_3, 1941		Bulk F_4 1942 No. Iowa	Spaced F_2 1940 (grams per plant)	F_5 lines surviving 1943	
	High parent	Low parent	Mean parent	F_2	F_3	F_4	F_5	Mean F_2–F_5	Bulk	Mean 41 F_3 lines			No.	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
15	49.3(1)†	45.1	47.2	47.1	39.3	38.9	43.2	42.1	37.0	34.6	25.3	37.9	22	58.0
18	49.1(1)	40.1	44.6	48.3	38.7	37.6	47.4	43.0	38.2	34.3	29.8	44.7	12	61.2
28	49.9(2)	39.1	44.5	44.4	33.3	37.2	43.5	39.6	39.2	32.2	23.9	39.8	1	58.0
31	52.6(3)	45.7	49.2	54.3	39.1	39.9	48.1	45.3	39.2	36.5	24.5	41.6	10	61.1
35	55.5(3)	43.3	49.4	46.9	38.3	42.1	42.0	42.3	35.2	33.0	27.0	40.1	3	55.7
37	54.8(3)	30.2	42.5	45.9	39.2	45.1	47.6	44.5	33.6	31.0	28.7	37.8	2	58.5
38	52.7(3)	40.7	46.7	53.7	38.2	39.6	43.3	43.7	39.3	34.7	27.5	45.4	4	61.3
41	49.8(1)	43.1	46.4	49.3	37.5	37.3	49.5	43.4	34.1	34.8	29.3	39.6	11	57.6
43	55.7(3)	40.0	47.8	52.2	42.7	41.5	44.3	45.2	35.9	35.5	26.0	39.9	2	53.1
45	43.4(4)	42.0	42.7	45.8	40.6	37.5	41.2	41.3	35.2	30.4	30.1	35.6	15	56.6
46	43.7(6)	42.7	43.2	46.7	40.0	42.1	43.3	43.0	35.2	30.8	25.8	35.6	3	57.2
47	44.0(4)	28.6	36.3	43.1	34.7	34.5	43.2	38.9	31.0	25.0	30.1	33.1	2	57.2
52	41.9(2)	41.8	41.9	47.6	37.0	41.0	37.7	40.8	35.5	30.7	22.9	35.7	4	59.9
56	49.4(6)	39.2	44.3	43.8	39.2	39.6	43.3	41.5	33.0	33.0	24.9	38.7	6	57.8
58	46.0(5)	42.3	44.2	48.9	40.0	35.5	42.8	41.8	30.5	32.1	30.5	39.5	17	55.2
59	45.2(5)	35.7	40.5	49.6	39.0	34.6	47.6	42.7	30.7	29.5	26.8	36.7	9	56.1
61	47.7(1)	44.5	46.1	51.4	35.9	41.0	41.2	42.4	36.8	33.5	27.2	40.9	4	58.8
L.S.D.‡														
5%	5.1	5.1	3.6	5.1	5.1	5.1	5.1	2.3	5.0	7.3	4.7	3.7		
1%	6.7	6.7	4.8	6.7	6.7	6.7	6.7	3.0	6.0	9.6	6.3	4.9		
$\bar{x}$	48.9	40.2	44.6	48.2	38.4	39.1	44.1	42.5	34.7	32.4	27.1	39.0		
r§				0.209	0.362	0.108	0.117	0.074	0.576*	0.223	0.174	0.544*		

L.S.D. (Bu./A.):	Probability 5%	1%
Among means of generations (17 crosses), high and low parents	1.2	1.6
Among generations, high and low parent within crosses	5.0	6.6

*Significant at the 5% level of probability.
†Variety designation number of high parent.
‡Least significant differences (Bu./A.) between any two means occurring in column.
§Correlation with means of surviving F_5 lines (column 15), 15 DF.

TABLE 3.—*Mean maturity in days after September 1 of 17 crosses in soybeans.*

Cross	F2 to F5 bulk population test, Ames, 1943								F3, 1941		Spaced F2, 1940	F5 lines surviving, 1943	
	Early parent	Late parent	Mean parent	F_2	F_3	F_4	F_5	Mean F_2–F_5	Bulk	Mean 41 F_3 lines		No.	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
15	18.7(5)†	31.0	24.8	29.8	31.5	33.7	30.3	31.3	29.0	23.1	22.8	22	27.6
18	27.5(8)	30.5	29.0	28.8	31.8	32.3	28.5	30.4	28.7	20.5	22.5	12	26.8
28	27.8(8)	28.3	28.1	29.8	32.2	34.8	31.0	32.0	31.7	24.9	21.6	1	23.0
31	31.0(1)	33.3	32.2	35.0	37.2	39.7	33.2	36.3	32.0	30.3	23.3	10	27.1
35	18.7(5)	32.7	25.7	33.7	33.0	36.7	29.7	33.3	30.7	25.8	22.3	3	22.3
37	9.3(7)	32.7	21.0	24.7	28.2	33.5	27.2	28.4	28.3	19.6	19.2	2	21.0
38	27.3(8)	33.0	30.2	32.8	35.8	38.7	30.7	34.5	32.0	25.5	21.5	4	26.5
41	27.2(4)	31.0	29.1	29.2	31.0	33.0	29.3	30.6	31.7	23.8	23.7	11	27.2
43	27.3(4)	33.2	30.2	32.2	33.7	36.5	31.0	33.3	33.3	28.9	22.8	2	19.5
45	19.0(5)	26.7	22.8	24.5	25.5	28.3	24.0	25.6	25.3	18.7	21.4	15	22.4
46	27.0(4)	27.5	27.2	31.2	33.0	37.8	28.7	32.7	32.0	24.3	22.3	3	24.5
47	9.5(7)	25.2	17.3	15.2	18.2	21.8	17.7	18.2	18.0	11.7	19.2	2	21.5
52	18.7(5)	28.3	23.5	31.0	32.3	35.0	29.3	31.9	32.3	24.1	22.3	4	27.5
56	19.3(5)	27.5	23.4	31.2	32.2	33.8	29.7	31.7	31.3	23.7	21.9	6	27.7
58	19.8(5)	26.0	22.9	24.7	27.0	32.2	26.5	27.6	23.0	19.4	21.3	17	25.6
59	19.2(5)	20.3	19.7	22.8	25.7	30.3	26.2	26.3	19.0	17.5	18.9	9	24.1
61	27.5(6)	30.3	28.9	32.0	34.8	37.0	31.0	33.7	31.3	27.8	22.7	4	27.3
L.S.D.‡													
5%	1.8	1.8	1.2	1.8	1.8	1.8	1.8	1.1	3.3	5.3	0.8	—	—
1%	2.3	2.3	1.6	2.3	2.3	2.3	2.3	1.4	4.4	6.9	1.1	—	—
$\bar{x}$	22.0	29.3	25.7	28.7	30.8	33.8	28.5	30.4	28.8	22.9	21.7		
r§				0.358	0.415	0.339	0.404	0.407	0.287	0.266	0.491*		

L.S.D. (days)	Probability 5%	1%
Between generation means (17 crosses), early and late parent	0.4	0.5
Between generations, early and late parent within crosses	1.4	1.9

*Significant at the 5% level of probability.
†Variety designation number of early parent.
‡Least significant differences in days between any two means occurring in column.
§Correlation with means of surviving F_5 lines (column 14), 15 D.F.

TABLE 4.—*Mean lodging of 17 crosses in soybeans.*†

Cross	F₂ to F₅ bulk population test, Ames, 1943								F₃, 1941		Bulk F_4 1942 No. Iowa	Spaced F_2 1940	F_5 lines surviving 1943	
	Least parent	Most parent	Mean parent	F_2	F_3	F_4	F_5	Mean F_2–F_5	Bulk	Mean 41 F_3 lines			No.	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
15	2.2(5)‡	3.2	2.7	3.0	3.2	3.3	3.2	3.2	3.2	2.6	3.0	1.5	22	3.0
18	3.2(1)	3.8	3.5	3.0	4.2	4.0	3.2	3.6	3.8	3.6	4.0	2.2	12	3.3
28	3.0(2)	3.3	3.2	3.2	3.8	4.0	3.2	3.5	3.3	3.6	4.0	1.9	1	3.0
31	3.0(1)	3.0	3.0	3.0	3.8	3.5	3.2	3.4	3.8	3.6	3.3	2.0	10	2.9
35	2.5(5)	3.2	2.8	3.0	3.0	3.5	2.8	3.1	3.0	2.9	3.7	1.5	3	2.3
37	1.8(7)	3.0	2.4	3.0	2.9	3.3	3.0	3.0	4.0	3.2	4.0	2.0	2	2.8
38	3.0(3)	3.8	3.4	3.2	4.0	3.8	3.5	3.6	4.2	3.6	4.3	2.3	4	3.2
41	3.0(4)	3.2	3.1	3.2	4.0	3.8	3.0	3.5	3.5	3.7	3.7	2.1	11	3.2
43	3.0(4)	3.0	3.0	3.2	3.3	3.5	3.0	3.3	3.5	3.6	4.0	2.1	2	2.7
45	2.5(5)	3.0	2.8	2.7	2.7	3.3	2.8	2.9	2.7	2.1	3.0	1.4	15	2.4
46	2.8(4)	3.5	3.2	3.0	3.0	3.3	2.8	3.0	3.7	3.3	3.3	1.8	3	3.1
47	2.0(7)	3.2	2.6	1.8	3.2	3.0	2.5	2.6	3.8	2.6	4.0	1.6	2	2.5
52	2.3(5)	2.7	2.5	3.0	3.5	3.2	2.8	3.1	3.3	2.7	3.0	1.6	4	3.0
56	2.2(5)	4.0	3.1	3.0	3.0	3.3	2.8	3.0	3.0	2.7	3.0	1.3	6	3.0
58	2.3(5)	3.3	2.8	3.0	3.5	4.0	3.2	3.4	3.0	2.6	3.3	1.6	17	2.9
59	2.3(5)	4.2	3.3	3.2	3.2	4.0	3.0	3.3	3.2	2.2	3.3	1.4	9	2.8
61	3.0(6)	3.2	3.1	3.2	3.8	3.7	3.0	3.4	3.7	3.6	3.3	2.1	4	3.6
L.S.D.§														
5%	0.5	0.5	0.3	0.5	0.5	0.5	0.5	0.2	0.6	0.8	0.8	0.3	—	—
1%	0.6	0.6	0.5	0.6	0.6	0.6	0.6	0.3	0.8	1.1	1.0	0.5	—	—
$\bar{x}$	2.60	3.32	2.90	2.97	3.41	3.57	3.00	3.24	3.45	3.07	3.55	1.79		
r¶				0.494*	0.689**	0.415	0.488*	0.621**	0.449	0.571*	0.000	0.560*		

L.S.D. (scores):	Probability 5%	1%
Between generation means (17 crosses), high and low parents	0.11	0.15
Between generations, high and low parent within crosses	0.5	0.6

*Significant at the 5% level of probability.
**Significant at the 1% level of probability.
†Lodging in scores from 1 (perfectly erect) to 5 (prostrate).
‡Variety designation number of least lodged parent.
§Least significant differences in scores between any two means occurring in column.
¶Correlation with means of surviving F_5 lines (column 15), 15 D.F.

thereby permitting elimination of entire impotent crosses. To determine the value of such inter-cross information in soybeans, the 17 crosses in this study were compared in several bulk population trials planted at normal rates. Yield, maturity, lodging, and height were studied, and the results obtained for these varieties are summarized in Tables 2 to 5, respectively. In each table the right hand column consists of means of surviving F_5 lines which were selected from a concurrently conducted pedigree selection study, results of which are reported later in this paper. Means of 41 F_3 lines from each cross, reported in column 11 of each table, are also from the pedigree selection study.

Considering the yields in Table 2, it is disturbing to note the lack of agreement between bulk population mean yields and mean yields of surviving F_5 lines selected from these crosses. This is illustrated by cross 43 which was second highest in average yield in the F_2 to F_5 bulk yield test, but only two lines remained in F_5 and they were low in yield. On the other hand, cross 52 was one of the poorest in yield in the bulk test, but its F_5 selections yielded among the best. To facilitate this comparison the correlations between the cross means of each bulk test and the means of F_5 lines have been inserted at the bottom of the table. These coefficients show that only in the bulk F_3 test conducted in 1941 were the cross means significantly correlated with the progeny means. Cross means of bulk F_2 and F_3 tests, however, tended to be correlated with the progeny means to a higher degree than F_4 and F_5 means. Another disturbing feature is the consistent lack of agreement between the performance of crosses in different generations tested in the same year, or the same generation tested in different years. For instance, comparison of bulk F_3 trials in 1941 and 1943 shows an utter lack of agreement, in fact the correlation coefficient between the two sets of means is $-.136$. Seed with which these two tests were planted came from the same lot, that for the 1943 test merely having been stored for two years in a cold chamber and was still of good germinable quality. Differential response of the bulk F_3 crosses to the two seasons, 1941 and 1943, was obviously great.

Table 3 shows that mean dates of maturity for the bulk generations of each cross are similarly not associated with those of the selected F_5 lines. Agreement in maturity between the bulk tests, however, is much better than that for yield. The correlation between the means of the two bulk F_3 tests in 1941 and 1943, for instance, was .897, a highly significant association. Bulk lodging and height means (Tables 4 and 5), seem quite consistently indicative of the performance of subsequent selections.

The bulk cross test in which the F_2 to F_5 generations of the 17 crosses were compared in 1943 affords an interesting study. The analyses of variance for the four attributes studied appear in Table 6.

Of interest is the highly significant "generations×crosses" interaction for each of the four variates. At first thought it might seem highly unlikely that bulk populations of crosses would not respond similarly in advanced generations when tested in the same year. However, before these results can be considered, another feature of the test must be noted. Referring again to Table 2 (columns 5 to 8),

TABLE 5.—*Mean height in inches of 17 crosses in soybeans.*

Cross	F_2 to F_5 bulk population test, Ames, 1943								F_3, 1941		F_5 lines surviving, 1943	
	Tall parent	Short parent	Mean parent	F_2	F_3	F_4	F_5	Mean F_2–F_5	Bulk	Mean 41 F_3 lines	No.	Mean
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
15	46(1)†	36	40.9	43	44	46	42	43.8	38	35	22	39.2
18	49(1)	39	44.2	47	47	46	46	46.4	35	34	12	42.1
28	47(2)	43	44.8	46	46	48	45	46.0	38	34	1	39.0
31	53(3)	47	50.1	50	51	55	48	51.0	39	37	10	44.9
35	54(3)	37	45.3	48	50	52	43	48.1	36	35	3	41.0
37	53(3)	37	44.7	49	51	57	52	52.3	40	34	2	46.5
38	55(3)	45	49.7	53	49	53	49	51.0	37	34	4	42.8
41	49(4)	47	47.7	48	50	51	51	50.0	38	35	11	42.7
43	53(3)	50	51.4	53	50	54	50	51.8	39	36	2	37.5
45	48(4)	36	42.1	44	42	45	41	43.0	36	34	15	39.5
46	51(4)	48	49.2	52	51	54	45	50.6	39	34	3	45.0
47	48(4)	35	41.7	40	44	46	43	43.2	36	30	2	45.3
52	47(2)	36	41.3	45	45	48	45	45.6	38	34	4	40.8
56	48(6)	37	42.7	45	46	44	41	44.1	38	34	6	40.5
58	44(8)	36	39.8	41	39	41	40	40.0	35	33	17	38.0
59	44(9)	35	39.7	42	43	44	41	42.3	35	32	9	37.0
61	49(1)	48	48.2	49	47	51	48	48.8	38	35	4	43.8
L.S.D.‡												
5%	4	4	2.6	4	4	4	4	1.7	3	—	—	—
1%	5	5	3.5	5	5	5	5	2.3	4	—	—	—
$\bar{x}$	49.2	40.6	44.9	46.7	46.6	49.1	45.3	46.9	37.6	35.1		
r§				0.343	0.573**	0.594**	0.517**	0.539**	0.422	0.003		

L.S.D. (inches)	Probability 5%	1%
Between generations means (17 crosses), tall and short parent	0.9	1.2
Between generations, tall and short parent within crosses	4.0	5.0

**Significant at the 1% level of probability.
†Variety designation number of tall parent.
‡Least significant differences (inches) between any two means occurring in column.
§Correlation with means of surviving F_5 lines (column 13), 15 D.F.

TABLE 6.—*Analysis of variance of yield, maturity, lodging, and height in bulk population test, Ames, 1943.*

	D. F.	Variance			
		Yield	Maturity	Lodging	Height
Whole plots (subplot basis):					
Replications	5	155.82**	34.80**	3.51**	128.60**
Crosses	16	73.84**	601.12**	2.50**	498.49**
Error (a)	80	23.32	5.39	0.24	13.72
Subplots:					
Treatments:					
Generations	3	2140.96**	627.00**	9.10**	249.67**
High vs. low parent	1	3793.48**	2655.00**	26.85**	3744.00**
Generations vs. parents	1	604.54**	3065.00**	10.43**	557.00**
Treatments × crosses:					
Generation × crosses	48	42.13**	7.67**	0.34**	17.17**
Parents × crosses	16	121.62**	11.53**	0.95**	72.75**
Generations vs. parents × crosses	16	56.62**	45.38**	0.43**	24.81**
Error (b)	425	19.53	1.75	0.17	10.18

**Significant at the 1% level of probability.

mean yields for all crosses followed an unusual advanced generation curve, the F_2 to F_5 generations yielding 48.2, 38.4, 39.1, and 44.1 bushels per acre, respectively. These data might cause one to question seriously the validity of the test. An examination of the coefficient of variation in yield, 10.2% for the subplots and 11.4% for the whole plots, would indicate there was not an excessive amount of unaccountable variation. The stand obtained in the field was uniformly good for all generations. No reason can be found for the irregularity of the advanced generation yields until an examination is made of the year in which the seed for each generation was grown, and the type of season encountered. These data are summarized in Table 7.

An examination of the above data reveals that the seasons of 1940 and 1941 were exceptionally favorable for the late types of soybeans. Whereas the 70-year average date of the season's first killing frost at Ames is October 6, the first frost in these particular years was 3 to 4 weeks later. Furthermore, comparison of the mean maturity date of the nine parental varieties in these studies throughout the 4 years shows that soybeans were more advanced in the first two seasons than in the last two. Probably as a consequence of these factors, a highly significant correlation between maturity date and yield resulted.

In 1942 a season of the opposite extreme was encountered. A cold, wet spring delayed soybean planting, retarded early growth, and thereby delayed the mean date of maturity of the parental varieties. A killing frost 12 days earlier than normal, therefore, resulted in a truncated selection against late-maturing genotypes. This is substantiated by the highly significant negative correlation between lateness of maturity and yield. In 1943, the year that the bulk population test was grown, the most "normal" of the four seasons was encountered. Although the first killing frost was slightly later than

normal, this was compensated by a relative delay in the stage of advancement of soybeans again caused by low temperatures and excessive moisture during the early part of the growing season. A significant but low correlation was obtained between date of maturity and yield.

TABLE 7.—*Seasons in which progenitor generations of bulk population test were grown, pertinent seasonal data, and associations of characters among varieties or lines.*

Generations grown in test	Years progenitor generations grown		
	F_2	F_3	F_4
F_3	1940	—	—
F_4	1940	1941	—
F_5	1940	1941	1942

Seasonal data	1940	1941	1942	1943
Date of killing frost	Nov. 7	Oct. 28	Sept. 24	Oct. 15
Av. date of maturity (9 parents)	Sept. 18	Sept. 19	Sept. 25	Sept. 23
Correlations†:				
Degrees of freedom	69	246	246	125
Maturity date and yields	0.520**	0.519**	−0.584**	0.215*
Maturity date and lodging	0.471**	0.501**	0.680**	0.651**
Maturity date and height	0.796**	0.551**	0.581**	0.222*

*Significant at the 5% level of probability.
**Significant at the 1% level of probability.
†Correlations for 1940 are on means of 71 varieties grown at Ames in a replicated test. Those for the 1941, 1942, and 1943 are from the pedigree selection test discussed later in this paper.

It should also be noted that regardless of type of season late-maturing genotypes consistently grew taller and were more lodging susceptible than early-maturing genotypes.

Differences in mean maturity dates for the four generations, at the bottom of Table 3, are consistent with the above data. Bearing in mind that 0.5 day's difference between these means is the highly significant level, the F_3 generation, which had undergone one favorable season for the selection of late types, was 2 days later in maturity than the unselected F_2. The F_4, having undergone selection for late types during two seasons, was 5 days later than the F_2. The F_5, although having been subjected to the same selection pressures as the F_4, was further grown in 1942 in which year selection trends were reversed, and the mean maturity date again was equivalent to that of the F_2.

In the light of the population changes in maturity date, changes in the other characters assume more meaning. This is evident in the greater mean height of the bulk F_4 generation and the increased mean lodging score in the bulk F_3 and F_4 generations for all crosses when compared with the F_2. Bearing in mind that only a moderate correlation between maturity date and yield existed in the season in which this test was conducted, the low yields of the later F_3 and F_4 populations, and the higher yield of the earlier F_5 are understandable.

Likewise, lodging susceptibility and height show identical trends with that of maturity.

Variability as a means of evaluating crosses.—Replicated trials of spaced F_2 and bulk populations of segregating generations of crosses provide a means of evaluating crosses as to their mean performance in certain characters. However, the plant breeder sometimes is confronted with cases of excellent segregates being derived from crosses with relatively low mean performance. This presents the question as to whether the variance among the segregates within a cross might not provide a clue as to the value of the cross as a progenitor of desirable segregates.

When crosses are carried forward as bulk populations no estimate of the variance of critical characters is, of course, possible. In this experiment, however, such an estimate was possible inasmuch as the same crosses studied as bulk populations also were studied concurrently by the pedigree selection method. In each cross the progenies of 41 F_2 plants were studied in a replicated test in the F_3 generation. F_3 selections were made in adjacent space-planted plots and on the basis of the performance of the F_3 lines, progenies of the superior lines were again compared in a replicated test in the F_4 generation. The variance of yield, maturity, lodging, and height was determined among lines of each of the 17 crosses in the F_3 and F_4 generations.

To determine the value of the variation within a cross as a criterion of its potentialities, comparisons were made of the variance for the several characters in the F_3 with mean performance of final selections in the F_5 (Tables 2 to 5). In this experiment variance in any of the characters studied was not associated with either the number of F_5 lines surviving, or their mean performance. For instance, of the 17 crosses, crosses 37 and 46 showed the greatest variance in yield of F_3 lines but had only five mediocre yielding lines surviving in the F_5.

It would seem logical to expect crosses exhibiting a comparatively high degree of yield heterosis in the F_1 to show a correspondingly high variance in yield of their progenies. In this experiment the degree of heterosis of crosses, in Table 1, was not associated with the variance of F_3 lines in yield. Neither were mean yields of the bulk populations (Table 2) correlated with the F_3 variance.

As no association was obtained between variances of F_3 or F_4 lines of crosses and performance of finally selected lines from the crosses, or between yield heterosis of crosses and variance of their F_3 lines, variances of the crosses are not presented. Variances, however, were also thought to be of interest in determining the importance of the selection employed in the early phases of this study. Consequently, means and standard deviations for yield, maturity, lodging, and height of all F_3 and F_4 lines in comparison with those selected within each generation for further testing are presented in Table 8. Although means differed and standard deviations of the selected F_3 lines group were smaller when compared to the total population of all F_3 lines, no material reduction in standard deviations was obtained in the following generation. The effect of selection on variability of the characters studied was minimal.

TABLE 8.—*Means and standard deviations of all F_3 lines (1941) and all F_4 lines (1942) in comparison with those selected within each generation for further testing.*

Item	F_3 Lines, 1941		F_4 Lines, 1942	
	Total	Selected	Total	Selected
Number	697	248	248	127
	Means			
Yield	32.44	35.43	46.87	51.66
Maturity	22.91	25.52	30.19	25.77
Lodging	3.07	2.88	3.10	2.86
Height	35.14	35.28	45.48	44.17
	Standard Deviations All Progenies of All Crosses			
Yield	5.22	3.32	5.86	2.90
Maturity	7.91	6.60	7.36	4.72
Lodging	0.77	0.60	0.52	0.56
Height	3.27	2.67	4.19	3.71
	Standard Deviations Progenies Within Crosses			
Yield	4.52	3.17	5.34	2.81
Maturity	6.60	5.76	5.83	4.08
Lodging	0.56	0.46	0.43	0.45
Height	2.90	2.49	3.29	3.21

INTRA-CROSS STUDIES

In the previously mentioned tests, differences among populations of crosses were examined with the thought in mind that this procedure might facilitate elimination of entire undesirable crosses. Next to be considered is the possibility of the early evaluation of segregates within a cross, thereby permitting the elimination of undesirable segregates. One question which must be answered is, how early can segregates be accurately evaluated for critical characters? Another is, how early are characters adequately fixed to permit rigorous selection?

Individual F_2 plant measurements.—The earliest possible evaluation of segregates consisted of measurements on individual F_2 plants. In order to permit proper plant expression, spacing of the F_2 plants was a necessity. When spaced, however, plants exhibited considerably different growth habits than when planted at regular rates. Furthermore, in other self-pollinated species, an interaction between genotypes and spaced vs. normal planting rates has been noted. With this in mind when setting up the replicated test of F_3 lines, two methods of planting (8-inch spacing and drilling at standard rates) were superimposed on the design as subplots. The analysis of variance appears in Table 9. A highly significant interaction of F_3 lines with the two methods of planting was obtained.

Even though it is known that genotypes yield differentially when planted at extremely different rates, it is of interest to determine how accurately single F_2 plant measurements predict the performance of their progenies. Maturity date, lodging and yield of single F_2 plants

TABLE 9.—*Analysis of variance of subplot yields in F_3 line test.*

	D F	Variance
Methods of planting	1	17141608**
Replications × methods of planting	2	94047**
F_3 lines × methods of planting†	728	2492**
Error	1456	1605

**Highly significant at the 1% level of probability.
†Includes 32 parent entries.

were correlated with those of their progenies as shown in the first section of Table 10. It will be noted that date of maturity of the single plants was consistently an excellent index of the maturity of their progenies. Yield of single plants exhibited only a moderate prediction value, and the lodging association was consistently low. Mean yield and lodging of all F_2 plants of a cross were, however, highly indicative of the mean performance of the subsequent F_3 lines.

F_3 and F_4 line trials.—In chronological order, after single F_2 plant evaluation, is evaluation of F_3 lines and, thereafter, of F_4 lines. Correlations of F_3 lines with F_4 lines and F_4 lines with F_5 lines appear in the other sections of Table 10. Of the characters studied, date of maturity of F_3 lines showed the highest prediction value for the performance of F_4 lines. Lodging and height showed reasonably good prediction values. Yield, however, showed a consistent negative association. This was undoubtedly due to the extreme difference between the 1941 and 1942 seasons which was indicated in Table 7. Late F_3 lines tended to have higher yields in 1941 whereas early lines were favored in yield in 1942. F_4 lines and F_5 lines also showed some degree of association in date of maturity, height, and lodging. Yield associations were of lesser magnitude. Correlations of maturity date with the other characters studied seemed of sufficient importance to warrant presentation in Table 11. In view of the three widely divergent seasons represented, it seems highly significant that lodging and height showed consistently positive associations with maturity date. Yield, however, fluctuated from highly significant negative to highly significant positive associations with maturity date in the different seasons. Interseasonal correlations of parental variety performance (bottom of Table 10.) provide additional evidence of extreme differential seasonal effect upon yield. Whereas interseasonal correlations for maturity, height, and lodging among parents in all cases was significant at least at the .05 level of probability, interseasonal yield correlations were nonsignificant in the last three years of these trials. Correlation of parent yields, although nonsignificant, was positive thereby showing better interseasonal agreement than the F_3–F_4 line correlations even though the maturity range of the parents and F_4 lines was approximately equal. As interseasonal correlations of parent yields were no greater than F_4–F_5 line associations, low interseasonal correlations would not seem to be attributable to the heterozygosity of these lines.

The progenies of two sister F_3 plants from each of 51 F_3 lines were included in the 1942 trial and, likewise, the progenies of two sister F_4

TABLE 10.—*Correlation of F_2 plants with F_3 lines (1941), F_3 lines with F_4 lines (1942), and F_4 lines with F_5 lines (1943) grown at Ames, Iowa.*

Cross	F_2 plants with F_3 lines				F_3 lines with F_4 lines					F_4 lines with F_5 lines				
	D.F.	Maturity	Lodging	Yield	D.F.	Maturity	Height	Lodging	Yield	D.F.	Maturity	Height	Lodging	Yield
15	39	0.373*	0.045	0.334*	30	0.607**	0.457**	0.514**	−0.163	20	0.181	0.802**	−0.010	0.037
18	39	0.467**	−0.052	0.443**	12	0.717**	0.659*	0.234	−0.208	10	0.827**	0.137	0.046	0.371
28	39	0.684**	−0.089	0.446**	2	0.882	0.854	0.160	−0.727	0	—	—	—	—
31	39	0.727**	0.040	0.140	15	0.315	0.177	0.567*	−0.159	8	0.137	0.515	0.199	0.348
35	39	0.686**	0.136	0.298	19	0.413	0.314	0.498*	−0.081	1	0.902	1.000**	0.462	−0.964
37	39	0.796**	0.245	0.446**	5	0.406	−0.526	−0.095	−0.041	0	—	—	—	—
38	39	0.760**	0.075	0.019	11	0.362	0.313	−0.177	−0.092	2	−0.508	0.854	0.158	0.560
41	39	0.371*	0.081	0.370*	14	0.660**	0.569*	0.252	−0.230	9	0.797**	0.692*	0.400	−0.483
43	39	0.749**	0.123	0.367*	12	0.579	0.366	0.018	−0.544*	0	—	—	—	—
45	39	0.587**	0.278	−0.206	16	0.750**	0.524*	0.403	−0.399	13	0.697**	0.851**	0.409	0.529*
46	39	0.746**	0.047	0.484**	4	0.820*	0.708	0.000	−0.273	1	−0.820	0.991	0.000	0.247
47	39	0.407**	0.267	0.109	0	—	—	—	—	0	—	—	—	—
52	39	0.738**	0.206	0.415**	13	0.516*	0.013	0.300	0.189	2	0.000	−0.414	0.000	0.474
56	39	0.759**	0.373*	0.115	21	0.660**	0.577**	0.616**	−0.328	4	0.659	0.604	0.031	0.542
58	39	0.647**	0.067	0.335	19	0.278	0.580**	0.521*	0.129	15	0.048	0.427	0.205	−0.223
59	39	0.679**	0.021	0.119	15	0.801**	0.649**	0.570*	−0.523*	7	0.009	0.905**	0.287	0.139
61	39	0.706**	0.304	0.370*	6	0.730*	0.383	0.711*	−0.011	2	0.486	0.913	0.892	0.302
All crosses...	695	0.721**	0.277**	0.392**	246	0.637**	0.485**	0.588**	−0.155*	125	0.380**	0.764**	0.422**	0.204*
Among crosses........	15	0.913**	0.824**	0.801**	15	0.900**	0.729**	0.823**	−0.071	15	0.505*	0.842**	0.716**	0.483*
Within all crosses....	663	0.650**	0.119**	0.280**	214	0.505**	0.408**	0.432**	−0.175*	93	0.321**	0.732**	0.202*	0.145
$\bar{X}$ of 2 sister selections..					49	0.748**	0.606**	0.669**	−0.104	49	0.485**	0.841**	0.482**	0.427**
$\bar{X}$ of parents	7			0.838**	7	0.984**	0.884**	0.916**	0.633	7	0.982**	0.803**	0.689*	0.361

*Significant at the 5% level of probability.
**Significant at the 1% level of probability.

TABLE 11.—*Correlation of maturity date with lodging, height, and yield among progenies of 17 crosses in the F_2 (1941), F_3 (1942), and F_4 (1943) generations.*

Cross	Maturity and yield			Maturity and height			Maturity and lodging		
	1941	1942	1943	1941	1942	1943	1941	1942	1943
15	0.506**	−0.375*	−0.199	0.392*	0.616**	0.318	0.632**	0.669**	0.388
18	0.364	−0.372	−0.592*	0.599*	0.770**	0.233	0.013	0.141	0.229
28	0.816	−0.226	—	0.994**	1.000**	—	0.974*	0.105	—
31	0.755**	−0.784**	0.438	0.740**	0.623**	0.378	0.594**	0.639**	0.639*
35	0.368	−0.750**	0.993	0.582**	0.484*	0.977	0.505*	0.534*	0.964
37	0.644	−0.500	—	0.701	0.480	—	0.478	0.820*	—
38	0.309	−0.456	0.847	0.730**	0.193	0.281	0.212	0.388	0.105
41	0.379	−0.490	0.166	0.098	−0.121	0.470	0.050	0.577*	0.567
43	0.752**	−0.575*	—	0.713**	0.129	—	0.066	0.755**	—
45	0.689**	−0.599**	−0.142	0.496*	0.146	0.188	0.656**	0.808**	0.663**
46	0.223	−0.849*	−0.887	0.098	0.117	0.025	0.623	0.000	0.990
47	—	—	—	—	—	—	—	—	—
52	0.198	−0.766**	0.737	0.496	0.490	0.945	0.485	0.371	0.000
56	0.618**	−0.500*	−0.940**	0.434*	0.337	0.231	0.610**	0.561**	0.734
58	0.496*	−0.507*	0.459	0.081	0.534*	0.272	0.708**	0.652**	0.535*
59	0.554*	−0.741**	0.420	0.650**	0.533*	0.291	0.492*	0.849**	0.628
61	0.782*	−0.621	0.623	0.667	0.425	−0.053	0.678	0.682	0.915
All crosses	0.519**	−0.584**	0.215*	0.551**	0.581**	0.222*	0.501**	0.680**	0.651**
Among means of crosses	0.518*	−0.621**	0.532*	0.704**	0.853**	0.174	0.564*	0.854**	0.760**
Within all crosses	0.529**	−0.585**	0.124	0.509**	0.385**	0.241*	0.476**	0.571**	0.599**

*Significant at the 5% level of probability.
**Significant at the 1% level of probability.

plants from each of 51 F_4 lines were compared in the 1943 trial. An examination of yield differences between the progenies of sister plants of the F_3 and F_4 generations should contribute information on the rate of fixation of the factors conditioning yield, and thereby indicate how extensively lines in this stage of inbreeding should be sampled.

Of the 51 pairs of lines from sister F_3 selections studied in 1942, 6 differed significantly (5% level = 7.8 bushels) and 9 highly significantly (1% level = 10.2 bushels). Of the 51 pairs of lines from sister F_4 selections, only 4 differed in yield significantly (5% level = 10.1 bushels) and none differed highly significantly. Factors conditioning yield appeared to have attained a high degree of fixation in the F_4 generation, and retention of more than one selection from an F_4 line did not seem justifiable. Jenkins (6) and Sprague and Bryan (8) in comparisons of relative variability among and within inbred lines of corn similarly concluded that possibilities for selection are much greater among than within lines.

DISCUSSION

The plant breeding study reported herein has certain weaknesses, some avoidable and others unavoidable, which undoubtedly influenced results to some degree. It must be recognized that these studies were conducted with a species particularly sensitive to photoperiod, and the results may not be applicable to species in which genotypes are not as greatly restricted in latitudinal adaption.

The field study of the F_1 generation was not conducted in the same year in which the bulk populations were tested or the surviving F_5 lines were evaluated. A higher degree of association between heterosis exhibited in the F_1 and performance of subsequent generations possibly would be obtained were the various tests conducted under closely similar environmental conditions. Furthermore, F_1 yields on individual plants were compared with subsequent generations grown in drill plots, whereas in the F_3 pedigree selection test it was shown that the genotypes responded differentially at these two methods of planting. However, had it been shown that replicated drilled F_1 plots would indicate yield potentialities of a cross, the expense involved in producing an adequate quantity of F_1 seed would probably make this procedure prohibitive in a practical soybean breeding program.

Probably one of the most serious weaknesses from the standpoint of a fundamental study was failure to sample randomly the distribution curves of the F_3 and later populations for the characters studied. Selection for all characters was practiced simultaneously and undesirable segregates were discarded, as would normally be practiced in a plant breeding program. Selection for all characters, however, probably was not equally rigorous. It is thought that selection for lodging resistance, particularly among the early maturing lines, was more severe than for the other characters. Selection for maturity date, yield, and height probably follow lodging resistance in decreasing order of intensity of selection. Regardless of the degree of selection it undoubtedly tended to cause reduction in associations from one generation to the next. Truncated selection for high yield, for instance, would result in retention of some lines which were high be-

cause of environmental effects. In the subsequent generation progenies of selections from such high lines would tend to regress to their mean. Correlations from one generation to the next would be biased toward zero by such "erroneously" classified lines, regardless of whether positive or negative correlations were normally obtained. In a comparison by Sprague (7) of top crosses of six S_0 lines of corn and their top-crossed F_1 family means, although correlations of 0.85 and 0.98 were obtained between the top crosses of S_0 and S_1 plants for yield and resistance to stalk breaking, respectively, in both characters S_1 top crosses of which the S_0 progenitors had been selected for either extreme showed a tendency to regress toward the mean. If environmental effects had not influenced selection in early generations in the present study, it is thought that larger correlations would have been obtained.

Reduction of variability within populations would be expected as selection was practiced. The magnitude of such reduction can be found in Table 8. Standard deviations of those selections saved were consistently lower than the standard deviations of all selections grown. However, standard deviations within crosses were not appreciably reduced from the F_3 to the F_4 generation.

The tendency toward negative correlations obtained in yield between the F_3 and F_4 lines was primarily attributed to gross seasonal variations. Had two similar seasons been encountered, it is quite possible that positive correlations of a significant magnitude would have been obtained. It is thought that the results reported are of special value in emphasizing the danger of selection for yield on the basis of early progeny tests conducted during a single season where "abnormal" seasons are likely to be encountered.

The objective scoring of a character in a heterogeneous population is difficult. When assigning the average maturity date to a bulk population, for instance, there is a tendency to overlook early, completely mature segregates which are obscured by the tall, late segregates not yet mature. It is thought that this difficulty resulted in assigning slightly later dates than actual to those crosses in which there was extreme segregation for maturity. Likewise, those crosses and lines which exhibited extreme segregation for lodging were probably scored slightly higher in lodging susceptibility than was warranted.

The validity of comparisons of bulk populations of crosses with performance of F_5 lines with respect to a certain character is somewhat questionable in that selection was conducted simultaneously for all characters in the pedigree selection test. Furthermore, character means were based on a widely varying number of F_5 lines in different crosses. In a certain cross, for instance, most high-yielding segregates might have been discarded because of extreme lodging susceptibility or lateness in maturity. Surviving F_5 lines might, therefore, not be truly indicative of the yield potency of the cross.

It is further thought that bulk population trials might be more effective if conducted in the specific latitude for which a new variety is sought. Of the crosses studied later tests have indicated that cross 45 (Mukden × Richland) has provided the most desirable agronomic

combinations. Two superior segregates have been obtained from this cross which will be released as varieties within the near future, one having identical maturity with Richland, the early parent, and the other 6 days earlier. A number of other selections from this cross closely approached these two selections in desirability. It is disturbing to note the consistently low yield of this cross in bulk population trials conducted at Ames. However, the trial in northern Iowa, the area in which the superior segregates are adapted, reveals it as having good yield potentialities. Cross 31 (Illini×Dunfield), on the other hand, has provided a superior selection for southern Iowa. It is notable that this cross yielded consistently well in central Iowa tests and very poorly in the northern part of the state.

Results obtained in this study would indicate, in general, that bulk population trials in soybeans, planted at normal rates, contribute but little more intercross information than replicated spaced F_2 plant trials on which individual plant determinations are made. Neither method permits adequately accurate evaluation of crosses to permit rigorous selection among crosses. Detection and elimination of crosses particularly inferior in lodging resistance or of unsuitable maturity range would seem possible.

A high degree of association between maturity dates of individual F_2 plants and F_3 lines justifies selection for this variate among the F_2 segregates. Replicated tests of F_3 lines appeared fairly effective in permitting further intra-cross selection for suitable maturity, height, and lodging resistance. Interseasonal yield associations illustrated the hazard involved in rigorous selection for yield on the basis of a single year's results when tests are conducted in regions where seasonal interactions can be expected. After the F_3 generation, selection among lines on the basis of yield did not seem to involve greater danger of misclassification than selection among homozygous varieties.

SUMMARY

Degree of heterosis as evidenced by seed yield of spaced F_1 plants was of limited value in predicting the yield potentialities of the 17 soybean crosses studied.

Means of individual plant determinations on spaced F_2 plants contributed significant intercross information on yield, maturity date, and lodging resistance of final selections evolved from the 17 crosses.

Bulk population tests gave reasonably accurate evaluation of crosses as to the potential lodging resistance and height of subsequent selections. They were found of little value in the prediction of potential yield or date of maturity. Crosses responded differentially when tested in the bulk F_2 to F_5 generations in all characters studied. Natural selection was of sufficient magnitude to give extremely irregular advanced generation curves.

Intra-cross information contributed by individual F_2 plant and replicated plant progeny performance was evaluated. Individual maturity date determinations of spaced F_2 plants were highly indicative of the maturity date of subsequent progenies. Yield determinations gave moderate and lodging scores poor estimates of progeny performance.

Replicated progeny tests of F_2 and F_3 plants, regardless of season, provided reliable prediction values for dates of maturity, plant height, and lodging resistance. Seasonal fluctuations caused sufficient variability in yield as to make single-season evaluation of lines on the basis of this character hazardous. Subsequent to the F_3 generation, interaction of lines with seasons, however, was no greater than obtained among homozygous varieties.

LITERATURE CITED

1. HARLAN, H. V., MARTINI, M. L., and STEVENS, H. A study of methods in barley breeding. U. S. D. A. Tech. Bul. 720. 1940.
2. HARRINGTON, J. B. Predicting the value of a cross from an F_2 analysis. Can. Jour. Res., 6:21–37. 1932.
3. ————. Yielding capacity of wheat crosses as indicated by bulk hybrid tests. Can. Jour. Res., C, 18:578–584. 1940.
4. IMMER, R. F. Relation between yielding ability and homozygosis in barley crosses. Jour. Amer. Soc. Agron., 33:200–206. 1941.
5. ————. Distribution of yields of single plants of varieties and F_2 crosses of barley. Jour. Amer. Soc. Agron., 34:844–850. 1942
6. JENKINS, M. T. The segregation of genes affecting yield of grain in maize. Jour. Amer. Soc. Agron., 32:55–63. 1940.
7. SPRAGUE, G. F. Early testing of inbred lines of corn. Jour. Amer. Soc. Agron., 38:108–117. 1946.
8. ———— and BRYAN, A. A. The segregation of genes affecting yield prepotency, lodging, and disease resistance in F_3 and F_4 lines of corn. Jour. Amer. Soc. Agron., 33:207–214. 1941.

The Effect of Fertilizers on the Chemical Composition and Quality of Dew-Retted Hemp Fiber[1]

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THE quality of hemp fiber is correlated with its chemical composition. In general, dew-retted hemp fiber contains about 70% cellulose, which leaves 30% of material classed largely as encrustants. These latter constituents vary with the variety, growing conditions, and degree of retting. As shown in a previous paper by the author (1)[3], the ultimate strength of the fiber as tested depends on the degree of retting or how far the removal of encrustants is allowed to proceed. Other workers (2) have shown the effect on tensile strength of the selective removal of encrusting material from the cellulose part of the fiber.

In hemp culture, plants grown on soil where the nitrogen level is high tend to produce weak, coarse fiber. Tobler (5) has shown in work on flax that nitrogen increases the cross section area of a single fiber, thickens the fiber wall, and loosens the fiber bundles. According to Schneider (3), anatomical formations of hemp are influenced by the nutrition of the plant, and potassium has a tendency to balance this formation. A study of the effect of fertilizers on fiber composition and quality, the correlation of quality with the constituents of the fiber, and the correlation of encrusting materials with cellulose content is presented in this paper.

MATERIALS AND METHODS

The fiber for this work was obtained from an experiment conducted by the Division of Cotton and Other Fiber Crops and Diseases, in cooperation with the Illinois Experiment Station, on a farm at Mt. Morris, Ill. Six replications having all possible combinations of nitrogen, phosphorus, and potassium in the ratio of 9–36–36 were used. All fertilizers were applied at the rate of 300 pounds per acre. The hemp was dew-retted and the fiber broken out by machine.

The procedure for determining fiber constitutents was the same as that used in the paper already cited (1) with one exception. Since the values for pectic substances by the decarboxylation method are known to be high because of carbon dioxide liberated from other sources in the long boiling period with 12% hydrochloric acid, a more accurate value was obtained by running a blank on hemp fiber free from pectic substances.

Combing with a wire brush, as described in a previous paper (1), was dispensed with in preparing the fiber for breaking strength determinations. Before breaking,

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[3]Figures in parenthesis refer to "Literature Cited", p. 816.

loose ends were removed by stripping the fiber between the thumb and index finger. Breaking strength of the hemp fiber was measured on the Scott tester, Model DH, on 25 centimeter length and conditioned at 65% ±1 relative humidity. Spool-type clamps were used and their distance from center to center was 7.5 centimeters.

EXPERIMENTAL RESULTS

The results shown in Table 1 are the averages of six replications of each fertilizer treatment. The average composition of the 48 samples accounts for slightly less than 93% of constituents of retted hemp fiber. The data show that dew retting produces fiber remarkably uniform in composition regardless of fertilizer treatment.

TABLE 1.—*Average chemical composition, fineness, and strength of retted hemp fiber from six replications as influenced by fertilizer treatment.*

Treatments	Cellulose*	Lignin	Pectic substances	Pentosans	Protein	Ash	Cm per gram of fiber†	Breaking strength‡
0-0-0...	67.6	7.13	6.71	3.70	3.67	3.07	1251.3	144.5
0-0-36..	68.8	7.19	6.59	3.71	3.38	3.06	1106.0	147.6
0-36-0..	69.8	6.96	6.63	3.72	3.30	3.11	1260.0	143.7
0-36-36	68.2	7.09	6.63	3.83	3.55	3.08	1337.6	147.8
9-0-0...	68.6	7.35	6.73	3.70	3.88	3.16	938.8	129.0
9-0-36..	67.6	7.27	6.63	3.75	3.88	3.05	1093.1	136.9
9-36-0..	67.7	7.51	6.57	3.73	4.01	3.30	1028.8	128.5
9-36-36	70.0	7.05	6.28	3.70	3.39	2.96	823.0	133.9
Average	68.5	7.19	6.60	3.73	3.63	3.10	1103.0	139.0

*Analysis on a dry-weight basis.
†Results on air-dry basis.
‡Breaking strength in kilograms per gram.

Fiber fineness as determined by centimeters per gram is shown in Table 1, while Table 2 shows a highly significant decrease in fineness

TABLE 2.—*Statistical analysis of the constituents, texture, and strength of retted hemp fiber as influenced by fertilizer treatment.*

Variance†	D/F	Means squares and significance							
		Cellulose	Lignin	Pectic substances	Pentosans	Protein	Ash	Cm per gram	Breaking strength
Block...	5	8.50	0.59	2.17**	0.03	1.24*	0.43*	49,095.62	583,89**
N.......	1	0.20	0.48	0.09	0.00	1.19	0.02	803,962.22**	2,296.33**
P.......	1	6.98	0.08	0.22	0.01	0.23	0.01	6,991.43	13.44
K.......	1	0.59	0.09	0.19	0.02	0.34	0.18	5,227.10	314.16
NP.....	1	0.03	0.03	0.16	0,02	0.02	0.00	156,443.59**	6.45
NK.....	1	2.21	0.39	0.06	0.01	0.25	0.12	284.70	28.52
PK.....	1	0.18	0.07	0.00	0.00	0.01	0.05	22,581.02	1.76
NPK....	1	28.68*	0.16	0.07	0.03	1.01	0.04	224,119.66**	9.90
Error....	35	6.05	0.26	0.29	0.03	0.41	0.13	16,588.97	115.03
Total....	47	6.24	0.28	0.47	0.02	0.50	0.15	43,525.55	205.60

*At 5% level.
**At 1% level.
†Computation obtained by analysis of variance.

of fiber from nitrogen-fed plants. The N×P and N×P×K interactions were highly significant.

The breaking strength data in Table 1 show that a definitely weaker fiber was produced where fertilizers containing nitrogen were used. When the data were analyzed by the method of variance shown in Table 2, plants fed nitrogen gave fiber which was weaker by a highly significant value. The effect of individual constitutents of hemp fiber on breaking strength is shown in Table 3. The correlation coefficient r is positive and significant for pectic substances and negative and highly significant for protein content of hemp fiber. Lignin approaches significance by a negative value. Cellulose shows the least variation when correlated with breaking strength. Pectic substances are associated with increased strength of the fiber. There is a significant positive correlation between breaking strength and fiber fineness as measured by centimeters per gram. No significance was found for correlations between chemical constituents of the fiber and fineness.

TABLE 3.—*Values of correlation coefficient r between chemical constituents and breaking strength, between chemical constituents, breaking strength, and centimeters per gram fiber and chemical constituents and cellulose for dew-retted hemp fiber.*

Constituents	Breaking strength	Cm per gram fiber	Cellulose
	r	r	r
Cellulose	−0.032	−0.141	———
Lignin	−0.263	−0.137	−0.663**
Pectic substances	+0.300*	+0.104	−0.156
Pentosans	+0.187	+0.101	−0.340*
Protein	−0.447**	+0.015	−0.558**
Ash	−0.171	+0.046	−0.405**
Breaking strength	———	+0.357*	———

*Significant value = .288.
**Highly significant value = .372.

Cellulose may be considered a primary component, while lignin, pectic substances, pentosans, protein, and ash are secondary constituents of hemp fiber. Table 3 gives the correlation of these secondary constituents with cellulose. Lignin, protein, and ash show a highly negative correlation coefficient. Pentosans show a negative significant r, while pectic substances are negative but not significant.

DISCUSSION

The main factors determining the quality of hemp fiber are variety, cultural conditions, and retting. In the United States, the Kentucky variety, which is of Chinese origin, is grown almost entirely. It is one of the larger growing varieties and, if allowed to make too much growth, produces coarse, weak fiber. Plant size may be controlled in normal years by choosing a not too fertile soil or, on infertile soil, by fertilizer treatment. Further, the size can be controlled by the seeding rate, since a heavy rate tends to hold down the growth. Table 1 shows

the results of nitrogen fertilizer where nitrogen-fed plants produced a coarser fiber of lower strength. In Table 3 the highly significant negative correlation coefficient between protein and breaking strength substantiates the nitrogen effect, since protein is indirectly the result of nitrogen nutrition. While the protein values in Table 1 do not reach significance when analyzed by the method of variance, they approach it, and a study of the table shows the three highest protein values are from nitrogen fertilizers. Overly productive soil, such as old sod land, generally produces coarse fiber of low strength. An analysis of the fiber grown on such soil invariably shows a high protein content.

One field in which the fiber was of little value because of low breaking strength gave a protein value of 7.44%, which is nearly twice as high as that of most good quality fiber. Table 3 which gives the correlation coefficients between breaking strength and the fiber constituents, shows a significant positive r between pectic substances and breaking strength, a positive r for pentosans but not significant, a highly significant negative r for protein, and negative r's for ash and lignin but not significant. From these results it can be concluded that those substances giving significant positive correlation coefficients are associated with strength of fiber and possibly contribute to the holding of the cellulose fiber bundles together like sized thread or cord (2). Additional support for this statement may be found in the work of Schneider (4) in which he found pectin was uniformly distributed in the fiber cell walls of hemp and acted as an adhesive or binding material, thus resisting disintegration of the fiber. Conversely, protein, ash, and lignin can be expected to add little to breaking strength.

Protein *per se* perhaps does not add to or take away from the strength of hemp fiber, but it is an indication of the type of growth which produced the fiber. A high protein content indicates luxuriant growth and fiber produced by such growth is invariably weak. Fiber from the top of the hemp plant is weaker than from lower down and here again this fiber comes from a greener actively growing part of the plant and is high in protein. High ash is also an indication of rank growth; therefore, a fair degree of correlation should be found between protein and ash. An analysis of the 48 samples summarized in Table 1 shows a significant correlation between ash and protein. Thus, high ash and protein are associated with rank growth which produces weak fiber.

High lignin is found in the weaker fibers. Examples of this are wood and coir fiber. Strong fibers which have very little lignin are cotton and ramie, while slightly higher in lignin content and strong are hemp and flax. Jute contains between 11 and 12% lignin and is considered one of the weaker bast fibers. The lignin in these fibers ranges from less than 1% for cotton to nearly 35% for coir fiber. Ridge (2) found that by selectively removing lignin from bast fiber, he did not materially affect the dry strength of the fiber.

Table 3 shows the correlation coefficients for fineness of fiber as measured by centimeters per gram of fiber and the chemical constituents; also, between fineness and breaking strength. The centimeters per gram and breaking strength gave a positive significant r which approached a highly significant value. None of the constituents of

retted hemp fiber reach significance when correlated with fineness. A negative sign for cellulose and lignin indicates a decreasing concentration of these constituents in the fiber with fineness. The positive sign for pectic substances and pentosans shows these encrusting materials increase with fineness of fiber. The correlation coefficient signs are the same for cellulose, lignin, pectic substances, and pentosans for both breaking strength and fiber fineness. Thus, the variation of these constituents on fiber quality becomes apparent. The data in Table 3 show a highly significant negative correlation coefficient between cellulose and lignin, protein, and ash and a significant negative r for pentosans. The coefficient for pectic substances was negative but not significant. The negative correlation coefficient shows that all encrustants are being depleted during retting, and percentagely cellulose is increasing. Actual analysis over varying periods of retting demonstrates this fact nicely. Although some of the correlation coefficients are too low to support strong relationships, they do show trends and help to confirm existing data.

While dew retting is necessary to free the fiber, the evidence on loss of encrustants shows the importance of not overretting where strength is of primary importance.

SUMMARY

Nitrogen fertilizers increase the growth of hemp and give greater yields of dew-retted hemp fiber, but at the same time the quality may be inferior because the fiber is coarser and weaker. The same may be said of hemp fiber produced on soil high in nitrogen. The cellulose content of the fiber was significantly increased where the complete fertilizer was used; however, during retting the more labile secondary constituents tend to level off in concentration regardless of fertilizer treatment. Correlation coefficients show that encrusting material plays a part in increasing or decreasing strength of fiber. Fineness of fiber as measured by centimeters per gram of fiber gave a significant positive correlation coefficient with breaking strength. Correlation between fiber constituents and fineness was not significant. All encrustants show a negative correlation with the primary fiber constituent, cellulose; and lignin, protein, and ash gave highly significant correlation coefficients while pentosans gave a significant r.

LITERATURE CITED

1. Hessler, Lyle E. Chemical composition and strength differences in dew-retted hemp fiber. Jour. Amer. Soc. Agron., 37:146–155. 1945.
2. Ridge, D. P., Little, A. H., and Wharton, J. Jute cellulose and the relation of jute encrustants to fiber and yarn strength. Jour. Textile Inst., 35: T 93. 1944.
3. Schneider, Kurt. Fertilizing, fiber content and decomposition capacity of hemp. Faserforschung, 16:120–126. 1944.
4. ———. Cause of glueing together in flockenbast and anatomical basis for pectin production in hemp and flax. Faserforschung, 16:108–120. 1944.
5. Tobler, Fredrick. Evaluation of manures for flax by a microscopic method. Z. Pflanzenernahr, Dungung, Bodenk., 31A:208–215. 1933.

The Dilution Method for Plot or Field Seeding of Grasses and Legumes Alone or in Mixtures[1]

PAUL E. LEMMON AND A. L. HAFENRICHTER[2]

MANY new grasses have been introduced or have been domesticated from the native vegetation for use in conservation seedings on agricultural or range lands. Many new mixtures have been developed for this use. Extensive testing in plots has been required. Some seeds are difficult to drill because they are small or because they are light and fluffy. Mixtures containing two or more grasses and one or more legumes frequently tend to separate in the drill box. Uniform distribution of pure seedings and of mixtures is desired especially in test plots. The seeding of mixtures in alternate rows with divided drill boxes is becoming more common, especially in trial plantings. In this case, control of the seeding for each species in the mixture is difficult by ordinary methods. Plot work would be facilitated if the seedings could be made without repeatedly calibrating the drill. A dilution method was developed whereby difficulties are obviated, uniform results are obtained, and application can be made to a large number of species when basic seed data are at hand.

The dilution method was based on the principles that a relatively large amount of inert material would be distributed with which the seeds were mixed and that force-feed drills deliver on a volumetric basis. Drill charges for each of the different seedings would then have the same total volume of material to deliver regardless of the species or mixture that was being seeded. Only one drill setting would be necessary even for a large number of different plantings. The drill charges were made by substituting seed for inert material on an equivalent volume basis.

The idea of using a diluent is not new. Sand, sawdust, and other materials have been used. Cracked and screened barley was used as the inert material for the dilutent in these trials. Several cracked cereals were tried. The cracked barley gave a product containing more angular particles and particles of different sizes. Both of these features are desirable in a dilutent that is to be used for seeds of different size and mixtures containing seed of different density. The barley was milled at 2,500 r.p.m. in a 26-inch swinging-hammer mill fitted with a 3/16-inch screen. The milled material was screened with a seed cleaner having three screens arranged as follows: 12/64, 9/64, and 6/30 wire, top to bottom, respectively. A fan speed of 175 r.p.m. gave a medium wind blast. No barley grew in any of the field plantings.

Several trials were made to determine the most desirable volume of material to deliver from the drill. A fluted-feed type of drill was used, although double-run drills should give the same results because they operate on the same principle. All seedings were made in 12-inch rows

[1]Contribution from U. S. Dept. of Agriculture, Soil Conservation Service, Pacific Coast Region. Received for publication May 31, 1947.

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TABLE 1.—*Comparisons between the volumetric and gravimetric methods for determining the amount of dilutent needed to make up 1/10-acre drill charges of 12 species.**

Species	Test weight per bushel, pounds	No. of seeds per pound pure	Trial number	Total amount of seed for 1/10 acre, pounds†	Amount of dilutent‡				
					For 1/10 acre, pounds	For drill charge			
						Calculated from gravimetric data, pounds	By volume, pounds	Difference	
								Amount, pounds	Per cent§
Medicago sativa	60	226,720	1	0.90	9.5	8.64	8.59	+0.05	0.5
	60		2	0.85	9.5	8.67	8.76	−0.09	0.9
Oryzopsis miliacea	54	1,500,000	1	0.44	9.5	9.03	9.03	0	0
	54		2	0.43	9.5	9.04	9.12	−0.08	0.8
Phalaris tuberosa var. *stenoptera*	43		1	0.66	9.5	8.61	8.58	+0.03	0.3
	43	340,000	2	0.78	9.5	8.43	7.52	+0.91	9.6
Hordeum bulbosum‖	38		1	2.00	9.5	6.46	6.35	+0.11	1.2
	38	46,000	2	3.00	9.5	4.89	4.82	+0.07	0.7
Bromus marginatus	27		1	1.59	9.5	6.11	6.45	−0.34	3.6
	28	90,000	2	1.46	9.5	6.46	6.65	−0.19	2.0
	27		3	1.52	9.5	6.21	6.15	+0.06	0.6
Sanguisorba minor	25		1	1.66	9.5	5.67	5.55	+0.12	1.3
	25	54,000	2	1.60	9.5	5.77	6.03	−0.26	2.7
	25		3	1.33	9.5	6.40	6.86	−0.46	4.8

Lolium subulatum	24		1	0.62	9.5	8.01	8.21	−0.20	2.1
	23	165,000	2	0.66	9.5	7.83	7.75	+0.08	0.8
Elymus galucus	23		1	1.90	9.5	4.74	5.24	−0.50	5.3
	23	131,000	2	1.88	9.5	4.73	5.36	−0.63	6.6
Elymus triticoides	19	175,000	1	1.58	9.5	4.70	5.54	−0.84	8.8
	19		2	1.77	9.5	4.06	5.30	−1.24	13.1
Festuca elatior var.	18		1	1.07	9.5	6.07	5.10	+0.97	10.2
arundinacea	18	230,000	2	0.92	9.5	6.52	6.70	−0.18	1.9
	19		3	1.05	9.5	6.27	6.99	−0.72	7.6
Bromus catharticus	18		1	2.38	9.5	1.87	4.83	−2.96	31.2
	17	48,000	2	2.41	9.5	1.23	1.11	+0.11	1.2
	18		3	2.50	9.5	1.40	None	—	—¶
Bromus mollis	14		1	0.75	9.5	6.41	6.31	+0.10	1.1
	10	265,000	2	0.78	9.5	4.95	5.28	−0.33	3.4

*Standard drill setting delivered 95 pounds of dilutent per acre in 12-inch rows.
†Amount varies within species account difference in live-pure-seed percentage.
‡Test weight of dilutent: For trial No. 1 = 57.7 pounds; for trials No. 2 and 3 = 58.4 pounds.
§Expressed as per cent of total volume equivalent to 9.5 pounds dilutent.
¶Volume of seed was greater than that of 9.5 pounds of cracked barley. This seed was not processed to a comparable stage of purty as that uised in either trial one for two.

and the most practical rate proved to be 95 pounds per acre. The drill was "wide open" for this rate. At other row spacings proportional rates of delivery would be obtained. By using this rate of seeding, the most uniform distribution was obtained for the range of seeds used at this nursery.

Two methods for preparing drill charges were compared, volumetric and gravimetric. The volumetric method was the more practical for small drill charges such as are used for plot work. The gravimetric method has application for field-scale plantings because the determination of volume is difficult when large amounts of seed and dilutent are involved. A comparison of results by the two methods was made for plot seedings. The plots used in this study were 1/20 acre in size. All drill charges were made for 1/10-acre plantings so that the drill would function at full capacity for the 1/20-acre plantings so that the drill would function at full capacity for the 1/20-acre plot.

For the volumetric method, 9.5 pounds of dilutent were weighed out. The required amount of seed for 1/10 acre was weighed and its volume was determined. An equivalent volume of dilutent was then withdrawn and the seed and remaining dilutent were thoroughly mixed to prepare the drill charge.

The gravimetric method requires that the test weight for both the dilutent and the seed be known so that the drill charge mixture can be made on the volume basis by calculation from weights. The weight of seed to be used is known. The weight of the dilutent is calculated from the formula:

$$D_2 = D_1 - \left(\frac{S}{T_1} \times T_2\right)$$

where D_1 = weight of dilutent if drilled alone; D_2 = weight of dilutent required when seed is added; S = weight of seed required; T_1 = test weight per bushel of seed; and T_2 = test weight per bushel of dilutent.

Substituting the values from Table 1 for *Phalaris tuberosa* var. *stenoptera* for a typical drill charge: $D_2 = 9.5 - \left(\frac{0.66}{43} \times 57.7\right) = 8.61$ pounds, the amount of dilutent required for mixing with 0.66 pound of Harding grass seed to plant 1/10 acre. By the direct volumetric method, 8.58 pounds of dilutent was used. Table 1 compares the results from the direct volumetric method and from the indirect method, using gravimetric values. All results were obtained by using the two methods for preparing drill charges in 1/10- acre lots. Twelve species were used and 27 comparisons are given. For 19 of the 27 comparisons the difference between the two methods is less than 5%. Three comparisons show differences greater than 10% but in each case this difference occurs only once out of two or three trials with the same species. Large differences occur more frequently with species that have large, light seeds that require processing and with recently domesticated species whose seeds still vary widely in quality among lots. Examples of the former case are *Bromus catharticus* and *Elymus glaucus* and of the latter *Elymus triticoides*. The differences were least with small, heavy seeds with a high live-pure-seed value. In such cases the seed is but a small portion of the total drill charge.

The results given in Table 1, along with others not recorded, allow the conclusion that the calculation of volume from gravimetric values is reliable. Its accuracy depends on known values for test weight. Wherever test weights are in doubt, they would need to be determined. The test weight for mixtures must always be determined because no practical method is at hand for computing it. No values for mixtures are given in Table 1, but many mixtures have been seeded by the dilution method with results as good as were obtained for seedings of single species and with better results than from direct seeding without dilution.

DISCUSSION

The dilution method has been used at the nursery of the Pacific Coast Region of the Soil Conservation Service for 3 years for both plot and field seeding. It has several distinct advantages. It facilitates the planting of several pure seedings and mixed seedings because only one drill setting is used. All that is required is the cleaning of the drill between seedings. More uniform distribution of seed of all sizes is obtained in plots and in the field than where direct seeding is used. Components of mixtures containing two or more grasses and one or more legumes are more evenly distributed than from direct seedings. All components of the mixture can be seeded from the grain box, obviating separate adjustments and calibrations of both the grain box drills and the grass seed attachment. Light, fluffy seeds and especially small seeds are easily handled. Seedings can be made in alternate rows using a grain box divider regardless of great differences in size or weight of seed.

No deleterious results have yet been noted that might be attributed to the use of a relatively large amount of inert organic matter. Apparently the amount used had no adverse effects due to the development of soil microorganisms, the fixation of nutrients, or the stimulation of insects or rodents.

Polyploidy and Winter Survival in *Panicum virgatum* L.[1]

ETLAR L. NIELSEN[2]

THE problem of polyploidy in relation to environment has received a good deal of attention during recent years. The opinion of some European workers that polyploid species, or races thereof, are better adapted to unfavorable environmental conditions has not been borne out completely by all workers. The results of the statistical study made by Löve and Löve (3)[3] regarding the chromosome numbers of plants from certain localities from Timbuctoo to Spitzbergen are clearly defined. These workers found a marked increase in the frequency of polyploid species as the latitude increased. This frequency also increased with a change from a temperate to a cold climatic region. They included in their summary the statement that, "It is suggested that this fact is the result not only of the relatively greater hardiness or adaptability of polyploids than diploids to more extreme climates, but also of the possibly relatively higher frequency of long-day or neutral reactivity to the photoperiod within the polyploids than within the diploids". Sixty-four per cent of the 87 species examined from the Arctic island of Kolguev were found to be polyploids by Sokolovskaya and Strelkova (7).

It may be questioned whether the conclusions based upon such data are entirely applicable to intra-specific chromosomal variation even though they appear clear and definite for inter-specific comparisons. Gustafsson (2) has recently discussed the possible relations and effects of glaciation upon the flora immediately before the ice sheets. He offered the suggestion that, "The diploids get destroyed because their mechanism of heterosis betrays them; in large populations cross-breeding (and its consequences) means an advantage, in isolated remnants it implies destruction. Thus what should be compared from a viability point of view, is not the polyploid status itself *contra* the diploid, but rather the polyploid biotypes *contra* the isolated sum of the inbred diploids still alive". Later in the same paper he points out that, "The inferences of polyploid superiority, involving, for instance, improved cold-hardiness effected by the polyploid state itself must be taken with great caution. For a fair comparison every genus and every flora must be examined separately".

Schwanitz (6), in his discussion concerning polyploidy and phylogeny, referred to the importance of heterozygosity as it relates to the hardiness of plants. This was considered to be an effective mechanism for selective action in the formation of genotypes tolerant to cold.

Some additional data pertaining to intra-specific polyploidy and

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[1]Results of cooperative studies between the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Soils, and Agricultural Engineering and the Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication June 2, 1942.

[2]Agronomist, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.

[3]Figures in parenthexsis refer to "Literature Cited", p. 827.

winter survival have been compiled and are presented in this paper. The observations are an extension of those published in 1944 when a report was made concerning the morphological and chromosomal diversity occuring in *Panicum virgatum* L. (5).

MATERIALS AND METHODS

A number of the lines of switchgrass discussed earlier form the principal basis of this paper. In addition to these, however, 23 other lines of unknown chromosome numbers will be referred to since they bear indirectly upon the problem.

Seed lots from the original collections and accessions were germinated in small bread pans containing sterilized soil. The seedlings were transplanted into individual plant bands containing unsterilized greenhouse compost when they were about 2 inches tall. Later these were transplanted into the field where they were established in rows 42 inches apart, the plants in the rows being spaced at 24 inches. The usual cultivation and hoeing was done to control weeds. Ten plants of each line were established in 1941, where such were available. These were grown upon the Hill Farms of the Wisconsin Agricultural Experiment Station. The soil of the site, Miami silt loam, was of low to moderate fertility. Such seedlings as developed were included in the plantings of those lines where the germination was low.

The observations reported upon cover the period from establishment until the summer of 1944. The nursery was discontinued during 1945.

It is recognized that low temperatures alone might not be the sole agent effective in plant elimination during the period of this experiment. It was not determined whether or not there were associated damaging pathogens that were operative during the winters which might have materially influenced plant survival. No evidence of such pathogens was seen, however.

RESULTS

Establishment and growth during the summer of 1941 were generally good. Only a few plants failed to survive. The surviving ones were mostly vigorous at the end of the first growing season. The following spring there was some evidence of winter injury, particularly to the lines of southern origin. The casualties were noted that spring. The growth performance during the summer following that of establishment was vigorous.

Additional detailed observations were made during the early summer of 1943. There had been considerable mortality, again particularly among the southern strains (Table 1). Plants were classified after growth of the surviving plants was well under way. Surviving plants of southern strains tended to be of poor vigor compared to those from more northerly areas, the principal exception to this generalization being an octoploid line, seed of which was originally collected near Bentonville, Ark., where the colony occurred on the sand flats adjoining the White River. One Nebraska line (1608) tended to be more like the southern lines than its more northern counterparts.

The final analysis, made in the summer of 1944, substantiated the observations of the earlier years. Excepting for the lines noted, very few plants of southern origin were still alive. There was little or no evidence of injury to plants of the northern lines.

The 23 strains of unknown chromosome numbers performed similarly (Table 2). Generally plants of accessions from Oklahoma and Arkansas failed to survive the winters at Madison, Wis. All of the 31 plants of four different lines from these strains winterkilled during

TABLE 1.—*Growth behavior of 40 lines of known chromosome numbers of Panicum virgatum at Madison, Wis.*

Acc. No.	Chr. No.	Performance						Source
		1943				1944		
		Good	Fair	Poor	Dead	Living	Dead	
1432	18	10	—	—	—	10	0	Chippewa Falls, Wis.
345	36	—	—	9	1	0	10	Stillwater, Okla.
345 D		—	9	1	—	0	10	Stillwater, Okla.
345 C		—	—	3	7	0	10	Stillwater, Okla.
1414		10	—	—	—	10	0	Chippewa Falls, Wis.
1411		10	—	—	—	10	0	Chippewa Falls, Wis.
1434		—	9	—	—	9	0	Chippewa Falls, Wis.
1429		10	—	—	—	10	0	Chippewa Falls, Wis.
1602		—	—	4	6	0	10	Vernon, Tex.
1599		—	—	10	—	0	10	Perkins, Okla.
1596		—	—	2	5	0	7	Stillwater, Okla.
1304		10	—	—	—	10	0	Mandan, N. D.
1602 A		—	—	2	1	0	3	Vernon, Tex.
1426		2	—	—	—	2	0	Chippewa Falls, Wis.
345 B		—	—	10	0	0	0	Stillwater, Okla.
1422	54	—	10	—	—	10	0	Chippewa Falls, Wis.
644		—	—	2	—	0	2	Edens Bluff, Ark.
25	72	—	10	—	—	10	0	O'Neil, Neb.
343		—	10	—	—	10	0	O'Neil, Neb.
345 D		—	—	6	3	1	8	Stillwater, Okla.
1047		—	10	—	—	6	4	Bentonville, Ark.
1305		—	10	—	—	10	0	Lincoln, Neb.
1330		—	10	—	—	10	0	Holt Co., Neb.
1329		—	10	—	—	9	1	Holt Co., Neb.
1326		10	—	—	—	10	0	Greeley, Colo.
1324		—	10	—	—	10	0	Greeley, Colo.
1413		9	—	—	—	9	0	Chippewa Falls, Wis.
1410		—	10	—	—	10	0	Chippewa Falls, Wis.
1608		—	—	7	3	7	3	Amelia, Neb.
1331		—	3	—	—	3	0	Greeley, Colo.
1425		—	2	—	—	2	0	Chippewa Falls, Wis.
339	90	—	10	—	—	10	0	O'Neil, Neb.
1327		—	10	—	—	10	0	Greeley, Colo.
1323		10	—	—	—	10	0	Greeley, Colo.
1409		—	8	—	—	8	0	Chippewa Falls, Wis.
1409 A		10	—	—	—	10	0	Chippewa Falls, Wis.
1597		—	5	—	—	4*	1	Perkins, Okla.
340		—	3	—	—	3	0	Greeley, Colo.
1322		1	—	—	—	1	0	Greeley, Colo.
1325	108	10	—	—	—	10	0	Greeley, Colo.

*All very weak.

the period that these progenies were under observation. One plant developed from the seed lot[4] procured from the Soil Conservation

[4]This represented a bulk seed lot, the exact origin of which was not available.

Nursery located at Winona, Minn., whereas two plants of line 1375 from Chippewa Falls, Wis., winterkilled. Otherwise survival was good among the northern strains.

TABLE 2.—*Growth behavior of 23 lines of unknown chromosome numbers of Panicum virgatum at Madison, Wis.*

Acc. No.	1943				1944		Source
	Good	Fair	Poor	Dead	Living	Dead	
	—	9	—	—	8	—	SCS, Winona, Minn.
1174	—	—	5	5	0	10	Paragould, Ark.
1343	—	—	8	2	0	10	Forest City, Ark.
1328	—	9	—	—	9	0	Lincoln, Neb.
1332	—	10	—	—	10	0	Chippewa Falls, Wis.
1419	10	—	—	—	10	0	Chippewa Falls, Wis.
1409	—	1	—	—	1	0	Chippewa Falls, Wis.
1417	—	6	—	4	6	4	Chippewa Falls, Wis.
1375	—	9	—	1	8	2	Chippewa Falls, Wis.
1379	—	10	—	—	10	0	Chippewa Falls, Wis.
1306	10	—	—	—	10	0	Chippewa Falls, Wis.
1594	9	—	—	—	9	0	Holt Co., Neb.
1604(9)	—	—	7	3	0	10	Perkins, Okla.
1382	—	8	—	1	8	1	Chippewa Falls, Wis.
1374	—	4	—	—	4	0	Chippewa Falls, Wis.
1373	—	8	1	—	9	0	Chippewa Falls, Wis.
1501	—	4	—	—	4	0	Chippewa Falls, Wis.
1458	9	—	—	—	9	0	Chippewa Falls, Wis.
1436	—	5	—	1	5	1	Chippewa Falls, Wis.
1424	—	3	—	—	3	0	Chippewa Falls, Wis.
1606	—	—	—	1	0	1	Perkins, Okla.
1475	—	8	—	—	8	0	Chippewa Falls, Wis.

DISCUSSION

These data may be of some significance to the problem concerning polyploid races and the geographical distribution of naturally occurring populations of plants. It is recognized that these tests were made under nursery conditions and that the populations examined were small. Nonetheless, the data raise certain questions, particularly as they pertain to the European school of thought. They suggest that among the northern strains there has been considerable elimination earlier of the weaker segregates that perhaps arose originally through inter-pollination of divergent biotypes. Some variants possessing divergent morphological characteristics have survived, become "stablized", and now constitute the polymorphic population of the species as it occurs naturally throughout the northern portion of its range. These, and their progenies, are sufficiently selected for this character of winter survival so that losses due to this factor are at a minimum.

The performance of the lines of southern origin suggest that there has been little tendency for the less hardy genotypes to be eliminated because of winter injury in the regions from which they were originally taken. Further, the data suggest that there was a general susceptibility to prolonged cold or low temperatures throughout all of

such material tested. Though the southern and northern biotypes that occur naturally in the range of the species in North America are considered as one species symstematically, one cannot but be aware of the prevailing coarseness and greater size that characterize much of the material from the more temperate region. This divergence is particularly evident when one sees the extremely different-appearing segregates of the two areas growing adjacent in the nursery. However, no evidence has been found to suggest the possibility of two specific entity complexes being involved (5). Until more critical means of distinguishing the major segregates occurring in this species are available, the southern and northern biotypes must be considered as of one polymorphic species. These data, though not extensive, would seem to indicate that in *Panicum virgatum* polyploidy is of little significance in phytogeographic distribution. This conclusion is fully in accord with the writer's earlier observations (5).

This viewpoint is similar to that of Clausen, Keck, and Hiesey (1) who state regarding several monocotyledonous and dicotyledonous species, "There is no observable correlation between degree of polyploidy and environment, for in some complexes the forms with low numbers are at high altitude, in others at low altitude, in some near the sea, in others, inland".

There appears to be some evidence among some of the other grasses that would tend to suggest that the condition just referred to may be fairly widespread throughout the Gramineae. A considerable number of cases are cited by Myers (4) wherein polyploid series of chromosome numbers occur in the same taxonomic species. Examination of a number of the papers from which these records were taken suggests also that, when one of the grasses has been studied extensively, and polyploid series occur, the different chromosome numbers often appear somewhat at random. Unfortunately, in much of the earlier work, the localities from which the plants or seeds were originally collected are not indicated.

The data given here, and those included in other reports of studies of intra-specific variation among the grasses belonging to several of the tribes, suggest that in these groups polyploidy may not necessarily be directly correlated with the ability of plants of a particular entity to survive in a region of unfavorable environmental conditions. It will be necessary, however, to study the variability that occurs within a considerable number of biotypes of a species, and of different species, from divergent localities wherein these occur naturally before broad generatilizations will be justified.

SUMMARY

Observations were made relative to the winter survival of plants developed from 63 accessions of switch grass, *Panicum virgatum*, taken origninally from scattered localities, particularly of the Great Plains region of the United States. These were grown in breeding nurseries at Madison, Wis. The data suggest that polyploidy in switchgrass is not directly associated with winterhardiness, or the ability of members of the polyploid series of genotypes to grow in a more rigorous environment than are their diploid counterparts.

LITERATURE CITED

1. CLAUSEN, J., KECK, D. D., and HIESEY, W. M. Regional differentiation of plant species. Amer. Nat., 75:231–250. 1941.
2. GUSTAFSSON, Å. The plant species in relation to polyploidy and apomixis. Hered., 32:444–448. 1946.
3. LÖVE, A., and LÖVE, D. The significance of differences in distribution of diploids and polyploids. Hered., 29:145–163. 1943.
4. MYERS, W. M. Cytology and genetics of forage grasses. Bot. Rev., 13:319–421. 1947.
5. NIELSON, E. L. Analysis of variation in *Panicum virgatum*. Jour. Agri. Res., 69:327–353. 1944.
6. SCHWANITZ, F. Polyploidie und Phylogenie. Biologe, 8:323–335. 1939.
7. SOKOLOVSKAYA, A. P., and STRELKOVA, O. S. Polyploidy and karyological races under conditions in the arctic. Acad. Sci. U.R.S.S., 32:144–147. 1941.

Notes

A SOIL SAMPLING MACHINE FOR OBTAINING UNDISTURBED CORES

DURING the spring of 1945, the authors undertook to determine the feasibility of obtaining undisturbed soil cores by a power-driven machine.[1] There have been a considerable number of machines developed for obtaining samples of earth. A rather complete review of soil sampling equipment was made in 1940 by Hvorslev.[2] The information contained in this article, however, does not provide a satisfactory method of obtaining undisturbed soil cores to shallow depth (from 0 to 6 feet). Further study revealed other sampling devices[3] none of which seemed suitable for obtaining undisturbed soil samples. Some of the principles of the various sampling devices, however, did seem to have merit.

An experimental soil sampler, therefore, was constructed after considerable trial and experimentation[4] which could obtain undisturbed cores of 2-inch diameter to a depth of 30 inches. A photograph of this machine (Fig. 1) shows the apparatus set in operating position prior to taking a soil core. Fig. 2 is a side view of the soil sampler taken from a complete set of working drawings for the purpose of showing the important parts of the machine and the working mechanism. It will be noted that all functions of the machine are not power driven. The operation of raising the machine from the horizontal to the vertical and *vice versa* are manual. The machine is augered into the ground by a short flight type helix section welded to the tip of the cutting head which is seen in Fig. 1, as well as by the weight of the motor and differential which moves with the auger assembly while the soil sample is being taken and removed.

Observe also in Fig. 2 that once the machine has taken a sample to the depth of 30 inches it is retracted from the ground manually by the cable and pulley which are attached to the front of the frame. While this machine is satisfactory for obtaining undisturbed 2-inch cores to a depth of 30 inches, it is not satisfactory from a mechanical point of view. This is particularly true in that there is still a considerable amount of manual labor in lowering and raising the machine and retracting it from the ground.

It must be remembered that the original objective of this project was to determine whether or not it was feasible to obtain undisturbed cores by a power-driven apparatus. This machine accomplished its purpose in determining that the taking of such cores was practical and feasible.

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[1]This initial work was done while the authors were conducting soil investigations on the Guayule Research Project, Salinas, Calif.

[2]HVORSLEV, M. JUUL. The present status of the art of obtaining undisturbed samples of soils. Committee on Sampling and Testing Soil Mechanics and Foundations Division American Society of Civil Engineers, Cambridge, Mass. 1940.

[3]Concore, Frank L. Howard Engineering Company, Los Angeles, California, core cutting equipment.

[4]Appreciation is expressed to Dr. A. C. Hildreth, Leader of the Guayule Research Project, and to Mr. Bill Allen, Mechanic, U. S. Forest Service, Region 5 shop at Salinas, California. Both of these men contributed in the development of the original machine.

Since then work has been conducted with additional cooperation from the Utah State Agricultural College and the Utah Scientific Research Foundation at Logan, Utah, in developing a soil sampling

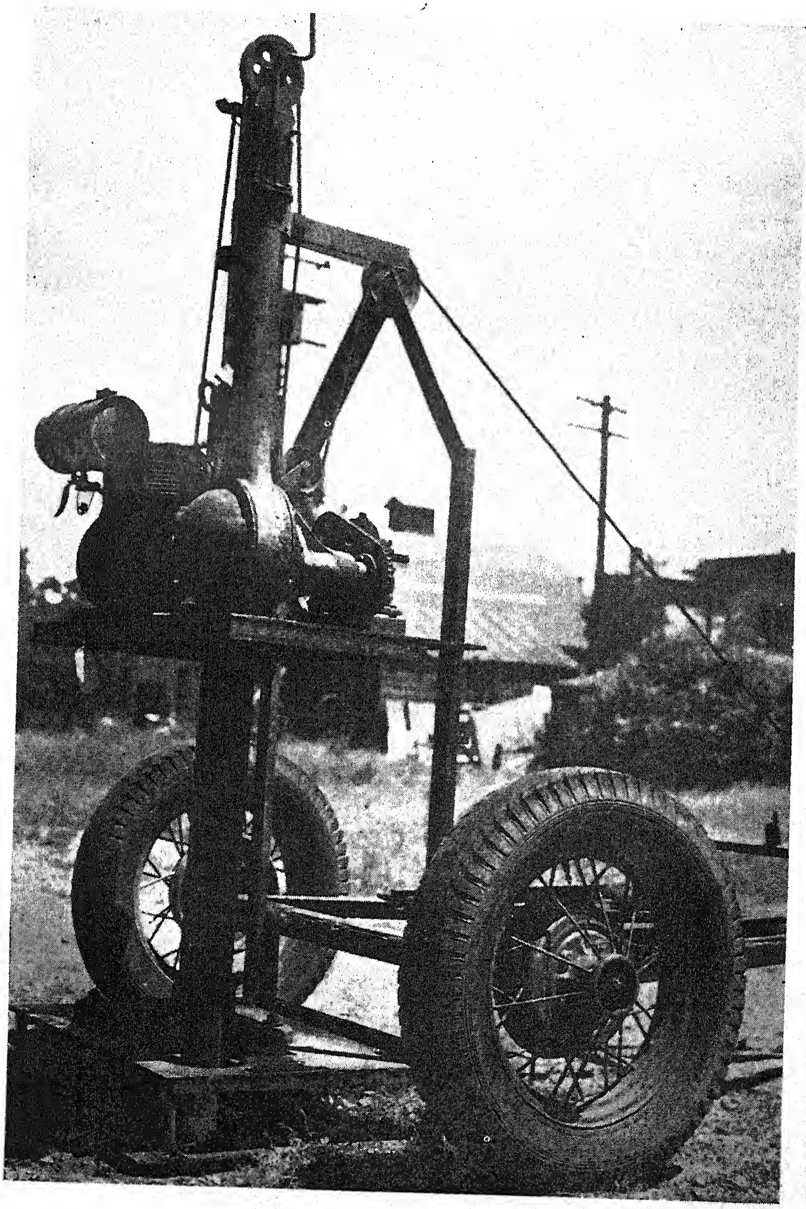

FIG. 1.—Power-driven soil sampling machine.

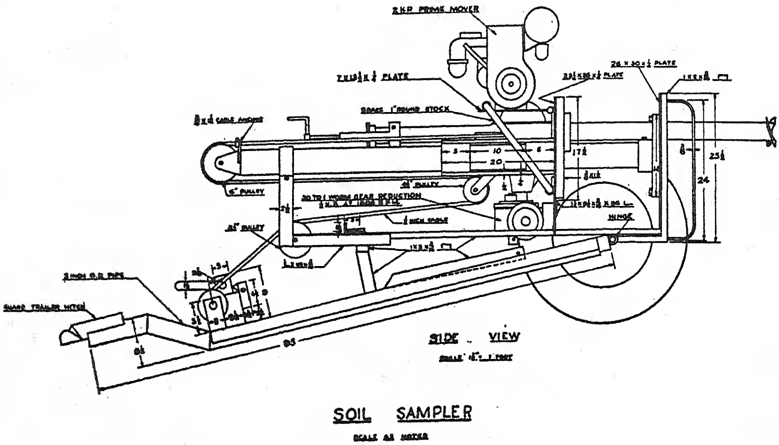

FIG. 2.—Working diagram of soil sampling machine.

machine for taking undisturbed cores to a depth of 6 feet in varying diameters of 2, 4, and 6 inches. Considerable progress has been made on this latter machine and it is expected that a complete description of it will be made in the literature in the near future.—OMER J. KELLEY AND HOWARD R. HAISE, *Utah State Agricultural College, Logan, Utah.*

ADAPTABILITY OF STRAINS OF SUBCLOVER TO ALABAMA CONDITIONS

HOLLOWELL[1] reported that about 15 varieties of subclover have been tested in the Southeastern states and Mt. Barker and Tallarook were found best adapted to this region. Rampton[2] described strain adaptions in Oregon, but no reports were found of strain differences in susceptibility to mildew.

Reseeding ability, comparative earliness, and disease resistance of four strains of subclover, *Trifolium subterraneum* L., were studied in plantings on Susquehanna Clay on the Tuskegee Experiment Field in central Alabama. These seedings were made in September, 1945, and a marked difference in resistance to powdery mildew was observed the following spring.

The Dwalganup strain matured early and died in April. The Bacchus Marsh strain approached maturity and was white with mildew about May 1, while the Mt. Barker strain showed only slight mildew. At that time Tallarook was growing vigorously and appeared completely resistant to the disease. There did not appear to be much difference in time of maturity of the Mt. Barker and Tallarook strains.

[1]HOLLOWELL, E. A. Personal communication. The Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, cooperated in these subclover tests, furnishing the seed and special inoculant.

[2]RAMPTON, H. H. Growing subclover in Oregon. Ore. Agr. Exp. Sta. Bul. 432. 1945.

These strains ranked about in the same order of susceptibility to mildew in 1947 as they did in 1946. June 9, 1947, when all of the strains were fully mature and had stopped flowering, Tallarook which was the most resistant showed very slight mildew.

The total rainfall during April, 1946, at Tuskegee was 1.83 inches and the mean temperature was 66.8° F. In 1947 the rainfall during April was 9.42 inches and the mean temperature was 67.1° F.

Subclover in pure seedings on fine-textured soils has shown promise as a reseeding winter annual legume for upland pastures in northeastern Alabama at the Alexandria Experiment Field, as well as in the test referred to above at Tuskegee. In other plantings, which were made on sandy soils in central Alabama, attempts were made to introduce the legume into established carpet grass, *Axonopus compressus*, and Bermuda grass, *Cynodon dactylon*, sods. Although lime, phosphate, and potash were applied in all of these tests, an insignificant amount of clover survived the competition of the grass longer than 2 years when seeded in established sods.—E. H. STEWART AND H. T. ROGERS. *Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala.*

SWEET CORN AN IMPORTANT INDIAN FOOD PLANT IN THE PRE-COLUMBIAN PERIOD

THIS short note has been written to refute an article by A. T. Erwin[1] which appeared in this JOURNAL. A full presentation of data will appear elsewhere,[2] but few who read this JOURNAL will see the other. It seems desirable, therefore, to publish this note here.

Erwin has three times stated his view that "sweet corn made its appearance in the United States as a food plant near the beginning of the nineteenth century";[3] (b) "is a mutation of field corn of post-Columbian origin";[4] and (c) with considerable deviation in 1946, "the author sees no reason to deviate from his previous conclusion that 'sweet corn was not an *important* food plant in the United States in the pre-Columbian period' "[5] (italics mine). The section quoted by Erwin from his 1934 paper contradicts the statement quoted by me from the conclusion of the same paper, and is again denied in his 1942 paper. I can not see how one can say sweet corn was an American Indian food plant (important or not is immaterial) and still claim that it appeared as late as the beginning of the 19th century.

Erwin is unwilling to accept historical references to sweet corn, ethnologists' reports that Indians consider sweet corn to be one of their aboriginal crops, and the occurrence of archeological sweet

[1]ERWIN, A. T. Sweet corn not an important food plant in the pre-Columbian period. Jour. Amer. Soc. Agron., 39:117–121. 1947.

[2]CARTER, G. F. Sweet corn among the Indians. To appear in *The Geographical Review*, April, 1948.

[3]ERWIN, A. T. Sweet corn—its origin and importance as an Indian food plant in the United States. Iowa State Col. Jour. Sci., 8:389. 1934.

[4]ERWIN, A. T. Anent the origin of sweet corn. Iowa State Col. Jour. Sci., 16:485. 1942.

[5]See footnote 1.

corn as evidence of the widespread pre-Columbian existence of sweet corn.

The historical account that he rejects[6] as "a legend that somebody told grandfather some four decades before" proves upon examination to be a most detailed account of a specific plant with marked characteristics. The writer of the account refers to the man reputed to be the introducer of the sweet corn in terms that suggest that he is not only known to the writer, but that he was still living at the time the account was written. Far from grandfather retailing what someone told him, it is much more likely that grandfather is telling what he knows from first-hand experience. Erwin has made much of the failure to find any mention of sweet corn in the journals of the Sullivan expedition which is alleged to have brought back sweet corn. But the original account does not mention a journal, and elaborate destruction of some secondary writer's reference to one does not invalidate the original account.

It is true that we lack other reports of sweet corn in the early colonial period. This may prove nothing more than that the coastal Indians lacked sweet corn. It proves nothing concerning other Indians and particularly leaves open the question of the occurrence of corn among the inland tribes. We have numerous good detailed accounts by careful ethnologists that claim sweet corn for the Iroquois and for the upper Missouri Valley tribes as an aboriginal food stuff. Some of these are quite early, e.g., Maximilian reported sweet corn as early as 1833 among the upper Missouri Valley tribes. This is an improbably early date for white men to have introduced it, and sweet corn was already embedded in ritual and used in non-European ways.

Erwin seems to have missed the significance of the non-American manner of the usage of sweet corn. In various parts of America it seems to have been used as a sugar substitute. This certainly suggests a pre-Columbian role for the crop.

The archeological evidence that Erwin rejects totals three separate finds of sweet corn among the Pueblo peoples of the Southwest. In view of the slight chances of survival of any recognizable corn grains, this seems significant. Included in the three finds, moreover, is one entire ear originally described by Erwin. It is difficult to see how such an ear of pure sweet corn could ever have occurred unless man was deliberately propagating the crop. Sweet corn has a place in the ritual of the modern Pueblo peoples, and most of the tribes claim that they have grown it from time immemorial. There seems to be little reason to doubt them or to doubt the statement of Whiting[7] that almost every Hopi family grows some sweet corn today.

Sweet corn probably was aboriginal among the Papago. It is widespread in and about the state of Jalisco in Mexico, and there too has such peculiarities of usage as to suggest that it is an old plant. Sweet corn of a distinct genetic type occurs in Peru, Bolivia, Chile, and northwest Argentina, and again seems to be so implanted in folk usage that it most probably is to be viewed as an aboriginal crop.

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[6]*Old Colony Recorder*, Plymouth, Mass. July, 1822.

[7]WHITING, A. L. Ethnobotany of the Hopi. Museum of North Arizona, Bulletin 15, Flagstaff. 1939.

The evidence, then, seems fairly clear that sweet corn was an aboriginal food plant in America and that it was at least fairly widespread. It seems to have been used primarily to supply a sweet material for a people who lacked both sugar cane and the honey bee. Labelling it as not an important food plant in pre-Columbian America is about the equivalent of labelling sugar cane as not an important food plant in the present world.—GEORGE F. CARTER, *Department of Geography, The Johns Hopkins University, Baltimore, Md.*

SWEET CORN IN THE PRE-COLUMBIAN PERIOD IN THE UPPER MISSOURI REGION

MAXIMILIAN, an explorer of the upper Missouri, referred to by Carter above, mentions sweet corn and the important role it played during the "green corn season".

The pertinent question is to what kind of corn does this term "green corn" refer. Was it *Zea Mays* L., commonly termed field corn, or *Zea Mays* L. var. *rugosa*, Bonf., currently called sweet corn?

Will and Hyde[1] who survey the corn of this region gives us the answer. "*Green corn is invariable called sweet corn*" by the early travelers. It really was the common species of *field corn*.

If sweet corn is to be regarded as a mutation of field corn, no doubt such mutations occurred at various times and places in both the pre- and post-Columbian period. It is mainly a question of whether it was the Indian or the white man who made any important use of them. Sweet corn was grown by 6 of the 18 tribes in the upper Missouri Valley. They may have used sweet corn as a substitute for sugar, as suggested by Carter.

Corn meal for torteas, tomales, etc., appears to have been the Indian's most important use of corn. Sweet corn meal is definitely inferior to that made from field corn. The waxy character of the kernel and its lack of brittleness renders it difficult to grind. Perhaps this fact gave the Indians the idea of calling it "gummy corn." The meal soon becomes rancid and lacks the storage quality of field corn meal.

Confusion in the sweet corn literature arises through the error of accepting *flavor* as a taxonomic character. Sweet is a loose term and merely denotes a substance agreeable to the sense of taste. Thus we have sweet peppers, sweet pickles. Flavor is not a taxonomic character and hence cannot be accepted as such in identifying plants.

Likewise, the term sweet has been loosely applied to both field and sweet corn in the literature. The Indians called our sweet corn "puckered corn" or "shriveled corn". Both of these terms are good in that they apply to a taxonomic character found only in *Zea Mays* L. var. *rugosa*, Bonf., currently designated as sweet corn.

In closing, may we add, the workers in the field of archeology have contributed much valuable information regarding the early history of our economic plants. In some cases, however, the problem requires checking from every possible angle and even after weighing the evidence pro and con, the answer involves a considerable degree of

[1]WILL, GEO. F., and HYDE, GEO. E. Corn among the Indians of the upper Missouri. 1917. (Page 117.)

speculation, a factor which should spur us on for the final answer.—A. T. Erwin, *Iowa Agricultural Experiment Station, Ames, Iowa.*

VEGETATIVE PROPAGATION OF KUDZU[1]

KUDZU, *Pueraria Thumbergiana* (Sieb. and Zucc.) Benth., has become important as a soil-conserving forage crop and several hundred thousand acres are now grown in the southeastern states. It is valuable as a stabilizer of eroding land, it is highly esteemed as a pasture crop, and it can be made into hay or silage.

Kudzu has been reported as occurring in China as far north as the Province of Chihli[2]. That is a region from which have come many Asiatic woody plants which are hardy enough in southern New England, but the stems of Kudzu are usually winterkilled here, although the entire plant is not killed and it grows again from the root.

Kudzu has, long been grown in southern New England as an ornamental plant. There is a kudzu in Amherst, Mass., which has been living in its present location for more than 30 years and it does not die back to the ground every winter. This spring, 1947, there was live wood in it 15 feet from the ground. This plant, growing on a trellis against a house, is sheltered from some winds, but it is not protected by snow as it would be if upon the ground, and it is possible that this individual represents a clone which is hardier than some.

As better or hardier clones are discovered or developed, their vegetative propagation will become increasingly important and it was with this in mind that the work discussed here was undertaken.

Stems from which cuttings were made, all new or current season's growth, were collected by Mr. Hrant Yegian. All came from the plant mentioned above.

Single-node cuttings were used. Each was so made as to consist of one node, its leaf, and axillary bud or short axillary branch, with internodes severed about 3 inches from the node. These were set closely together in the rooting media in a greenhouse bench.

Indolebutyric acid was applied to cuttings either by the solution-immersion method or by the powder-dip method. In the latter case, the nodal parts of the cuttings, after being wetted, were dipped in a powder, i.e., Hormodin, containing indolebutyric acid.

The greenhouse used is equipped with an automatic humidifying unit and the propagating bench was shaded on the south on sunny days by white cotton curtains. The humidifying unit could be dispensed with if benches were watered sufficiently often. To help maintain a relatively high humidity, ventilation was kept at a minimum and air temperatures often rose to 90° to 100° F on sunny days.

Cuttings of kudzu taken on September 5 and 19, 1946, failed to root without treatment but rooted 100% in sand in 3 weeks after treatment with Hormodin No. 1. This was probably too late in the growing season, however, for these rooted September cuttings failed to make top growth and there was a high mortality among them during the winter in the greenhouse.

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[1]Massachusetts Agricultural Experiment Station Contribution No. 625.

[2]Porterfield, W. M. Ko, the kudzu-vine, provides food, shade, clothes and medicine. Jour. New York Bot. Gard., 39:465:203–205. 1938.

Cuttings were next taken on July 12 of the following year. The rooting of these cuttings in sand was hastened by treatment with Hormodin No. 1. In 12 days, there was 67% rooting of the treated cuttings and 38% rooting of the untreated cuttings. The untreated cuttings rooted well finally, however, with 80% in 19 days, with treated cuttings giving a final rooting of 87%. Treatments with Hormodin No. 2 or with indolebutyric acid 50 mg per liter of water for 18 hours gave inferior results.

The most numerous and longest roots were on cuttings made from the more proximal parts of shoots. The poorest roots were on untreated cuttings made from the more distal parts. Roots on cuttings which had received powder-dip treatments were mostly confined to the region of the node, the part treated, and they proved quite adequate.

Cuttings were next taken August 16. All were treated with Hormodin No. 1. In 4 weeks there was 83% rooting in sand, 100% in either sand-peat or Vermiculite. The roots in sandpeat (3:1 mixture) were superior to those in sand.

As soon as all living cuttings had rooted, they were transplanted to pots of soil in the greenhouse. The rooted cuttings which had made the most top growth by the following spring were those which, at the time they were taken, already bore a short axillary branch rather than an axillary bud only. There was almost no mortality of July and August cuttings which were kept through the first winter in the greenhouse. They were set in the field in June.

It is concluded that kudzu may be propagated by single-node cuttings, with a short axillary branch, made from the basal parts of the current year's growth in early or midsummer, treated with Hormodin No. 1, and rooted in sand-peat.—W. L. DORAN, *Massachusetts Agricultural Experiment Station, Amherst, Mass.*, and A. B. BEAUMONT, *Soil Conservation Service, U. S. Dept., of Agriculture.*

A SPRAYER ATTACHMENT FOR RAPIDLY APPLYING SMALL QUANTITIES OF SPRAY MATERIALS[1]

IN various phases of experimental work it is often necessary to apply accurately many different materials as sprays on small areas. It is suggested that the apparatus (Fig. 1) described below may be a useful means of accurately applying many spray materials over small areas in a relatively short period of time without waste of material.

The apparatus consists of a cylinder from a small pressure grease gun sealed at one end after removal of the plunger mechanism. A brass cap, threaded to screw onto the cylinder, is fitted with an air intake connection and an outlet for the spray material. A brass rod extending to the bottom of the cylinder is threaded into the brass cap, and a gasket placed in the top of the cap. The outlet and inlet connections accommodate regular sprayer fittings and a small petcock may be attached to the outlet if desired.

[1]Contribution from the Soil Science Section of the Michigan Agricultural Experiment Station, Michigan State College, East Lansing, Mich. Authorized for publication by the Director.

The attachment when in operation replaces the nozzle on the hose of a conventional type 3- or 5-gallon hand sprayer. The spray material is placed in the cylinder and when the desired pressure is built up by the hand pressure pump and the hand-operated valve in the sprayer hose released, the sprayer then operates in the usual manner, except that spray material is forced from the auxiliary cylinder rather than from the tank itself. The cylinder capacity is approximately 135 cc, but cylinders of greater or smaller capacity may be substituted if desired.

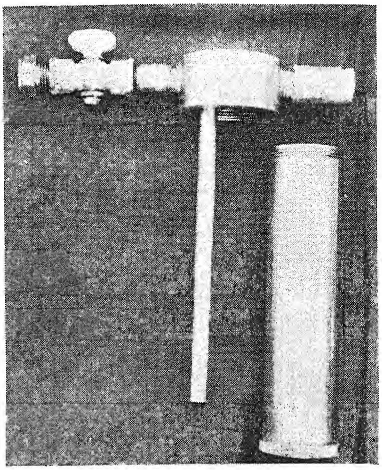

FIG. 1.—A spray apparatus designed for applying spray materials on small areas. A conventional 3- or 5-gallon hand-operated sprayer supplies the air pressure required in its operation.

The uniformity of application will depend on the skill and experience of the operator. Very little time is required to force small amounts of material from the cylinder so it is necessary for the operator to correlate the movement of the sprayer with the area to be covered to insure uniformity in coverage. The importance of this timing factor varies directly with the coarseness of the nozzle used.

It is possible to use a regular air line if available as a source of pressure. However, by taking advantage of the conventional type of hand sprayer as a source of air pressure, the scope of the apparatus is greatly increased, since air line facilities are oftentimes not at hand.

One distinct advantage of this design, in addition to the adjustment allowing selections of nozzle sizes, is the ease of cleaning. The entire assembly may be immersed in the cleaning solvent and thus speed up the time ordinarily required for the cleaning operations. In view of the fact that it is possible to force out the required amount of spray for a small area by placing this calculated amount in the small cylinder, very little waste of spray material results.

This equipment provides a rapid means for accurately applying spray materials over small areas, such as encountered in some greenhouse investigations.—J. F. DAVIS, *Michigan State College, East Lansing, Mich.*

Book Reviews

MANUAL ON FERTILIZER MANUFACTURE

By Vincent Sauchelli. Baltimore, Md.: Davison Chemical Corp. 126 pages, illus. 1947. $4.00.

According to the author, "this handbook was prepared for the man in the fertilizer works not too well trained in chemistry but who is interested in one way or another in the preparation of good commercial fertilizers that will best satisfy the farmer."

A brief introductory chapter covering some of the fundamentals of soil science and plant nutrition is followed by a short discussion of the properties of mixed fertilizers. Then the author gives comprehensive coverage of various nitrogenous materials, ammoniation of superphosphates, and the factors affecting reversion of ammoniated superphosphates.

A good discussion of phosphatic materials and the chemistry of superphosphate manufacture is climaxed by a rather detailed description of the equipment used by the Davison Company at Curtis Bay, Md.

Following short chapters on potassic materials and the secondary or minor elements is an excellent section on compounding fertilizers. Subjects covered include types of fertilizer plants, water relationships, curing and hardening of mixed fertilizers, hygroscopicity of fertilizer materials, compounding, ammoniating, and dry mixing to grade, conditioners and fillers, bag rot, and acidity and basicity of fertilizers.

A discussion of computations used in the formulation of mixed fertilizers and an outline of fire and explosive hazards is followed by a section containing miscellaneous information pertaining to fertilizer manufacture.

The 58 tables and 31 figures and illustrations which are included in the book contain a mass of data pertaining to fertilizer materials, useage, and manufacture. In spite of several errors, this is an excellent handbook for those men in the fertilizer industry for whom it was written, and in addition is a desirable and valuable reference for workers in the fields of soils and fertilizers.—M. T. Vittum.

PRACTICAL EMULSIONS

H. Bennett. Brooklyn: Chemical Publishing Co. XVI 568 pages, illus. 1947. $8.50.

This book deals with the practical art of making emulsions and using them in industry. Part I begins with a very good treatment of emulsion stability, formulation, methods, and equipment. This is followed by comprehensive lists of emulsifying agents, dispersing and wetting agents, and (what is much more difficult to find) a list of demulsifying and defoaming agents. A symposium of 13 papers on emulsifying agents and emulsions in industry makes up Part II. Part III, comprising the greater half of the book, gives examples of

the use of emulsions in such widely varied industrial fields as cosmetics, drugs, polishes, waxes, lacquers, textiles, leather, paint, food, etc.

Of particular interest to readers of this JOURNAL would be the chapter devoted to agricultural sprays. Unfortunately, this is one of the least useful portions of the book. Poorly organized and repetitious, many of the formulas are of little value because no mention is made of the plant and pest for which they are intended. The mildew spray on page 259 would injure severely most plants, and none of its active ingredients are currently recommended for controlling mildews.—GUILFORD L. MACK.

LAND FOR THE FAMILY

By A. F. Gustafson, E. V. Hardenburg, E. Y. Smith, and Jeannette B. McCay, New York: Comstock Publishing Company, Inc. XXII+501 pages, illus. 1947. $4.00.

THE authors are or were all formerly connected with the College of Agriculture of Cornell University and are well qualified for writing a book of this type. In the introduction they state that the book is intended for town and city poeple who are thiniking of going to the country to live, or former city dwellers who are already there and wish to produce some or more of their own food on the farm. It is stated that the book is not intended for those who are engaged in commercial agriculture.

The scope of the book is well expressed by the chapter heads which follow: Selecting and purchasing a home in the country; managing the soil; using manure, lime, and fertilizer; choosing the crops to grow; the vegetables garden; special problems and practices in vegetable gardening; fruit growing; flowers and ornamentals; producing feed crops; producing chickens and eggs; raising turkeys; ducks, geese, squabs, and guinea fowls; the family milk supply; the family meat supply; woodlands and wildlife; producing honey for home use; the kitchen; food for the family; canning food; freezing food; salting, drying, and curing food; and fruit juices, spreads, and relishes.

The book is illustrated with over 200 photographs and diagrams and is written in nontechnical language. An extensive reference list is given at the end of each chapter. This should be of great help and convenience for those wishing detailed information regarding certain subjects. There is no question but what this book should be an invaluable guide for the intended readers. Not only the advantages but also the disadvantages and pitfalls connected with living on the land are discussed in considerable detail.—E. TRUOG.

CITROCRAFT

By George R. Schultz, McAllen, Texas: Texas Soils Laboratory. XV+237 pages, illus. 1947. $5.

IN the introduction the author states "This book is not meant to be a technical or scientific publication. It is written for the rank

and file grower of the Valley." By the "grower of the Valley" is meant the citrus grower of the Rio Grande Valley of Texas. Accordingly, much of the discussion is directed towards the problems of the citrus grower as they occur locally in that Valley. Nevertheless, the book should be of great interest and value to citrus growers in general. The author heads the Texas Soil Laboratory which makes soil tests and carries on investigations for citrus growers of that Valley. This has made it possible for the author to present a great deal of first hand information that has special and direct application for that area. Because of this, the book should be an invaluable aid in helping the growers to solve their innumerable problems, especially those connected with salinity.

The book represents an excellent presentation in layman's language of citriculture under the condition of the Rio Grande Valley. It is well illustrated, although some of the illustrations, as for example the one showing soil profiles on page 61, are not too well designed. There are nine chapters in the book dealing successively with the fruit itself as grown in the Valley, the nature of the citrus tree, the characteristics and properties of soils, the use of water, the nature of chemical compounds and reactions, the plant nutrients, and salinity and its control.

A number of errors in spelling, English, and statements of figures occur. For example, on pages 14 and 94 we find "existence" and "inocculated" respectively; on page 97 we find "the amount of healthy water", which implies that water itself can have good and poor heatlh; on page 52 in a tabulation it is indicated that 1 kilometer equals 0.621 square feet; on page 176 it is indicated that it takes 500 pounds of water for the production of 1 gram of dry plant tissue; and on page 186 in the footnote, that 1% equals 1,000 parts per million. Obviously critical proofreading was lacking in the preparation of the book, and these matters need due attention in future editions.—E. Truog.

Agronomic Affairs

STANDING COMMITTEES OF THE CROPS SCIENCE DIVISION FOR 1947

VARIETAL STANDARDIZATION AND REGISTRATION

M. A. McCall, *Chairman*
H. K. Hayes
R. E. Karper
W. J. Morse
J. Allen Clark
F. N. Briggs
J. F. O'Kelly
L. F. Graber
T. R. Stanton
T. M. Stevenson
G. H. Stringfield
H. M. Tysdal

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

E. R. Ausemus, *Chairman*
J. B. Harrington
L. P. Reitz
E. R. Sears
S. P. Swenson

CROP TERMINOLOGY

C. J. Willard, *Chairman*
C. P. Wilsie
G. H. Ahlgren

TURF

F. V. Grau, *Chairman*
E. B. Cole
Gordon Jones
R. H. Morrish
H. B. Sprague
G. O. Mott
H. B. Musser
O. J. Noer
A. E. Rabbit
H. A. Schoth
M. E. Farnham

Erratum

IN the article on weeping lovegrass by W. H. Cummings in the June, 1947, issue of the JOURNAL on page 522, second line and on page 528, second line, East Africa instead of South Africa is the correct source of weeping lovegrass.

American Society of Agronomy JOURNAL

VOL. 39 OCTOBER, 1947 NO. 10

Effect of Fertilization on the Nitrogen, Calcium, and Phosphorus Contents of Pasture Herbage[1]

F. W. SHERWOOD, J. O. HALVERSON, W. W. WOODHOUSE, AND F. H. SMITH[2]

IN recent years considerable emphasis has been placed on the soil-plant-animal relationship. Many instances of nutritional failure of animals have been traced to soil deficiencies. Even in areas where the nutritive status of grazing animals is apparently normal, rather marked variations in the chemical composition of the forage have been observed. What the nutritional significance of these variations may be has not been adequately tested by carefully planned feeding experiments.

Abundant evidence exists which shows a complex interrelationship between the composition of pasture plants and the type and characteristics of the soil, the amount and availability of plant nutrients, the climatic conditions, including amount of precipitation and its distribution, the species and variety of plant and its stage of maturity, the frequency of cutting, and other cultural practices. The literature on the various phases of soil-plant-animal relationships is too voluminous to cite here. Those parts of the subject that are particularly pertinent have been reviewed by Beeson (2),[3] Browne (3), Kraus (7), and Russell (10). Numerous contributions to one or more phases of this subject have appeared since some of these reviews were written, but they only offer additional evidence and do not alter the interpretation of the older data.

Pasture soils in general, particularly in humid regions, are apt to be deficient in phosphorus. In some localities, the deficiency is so acute that cattle subsisting exclusively, or nearly so, on the native forage suffer from aphosphorosis. The application of phosphatic fertilizers to most pasture soils results in an increased yield of dry matter which may contain a larger percentage of phosphorus and nitrogen (crude protein).

[1]Contribution from the North Carolina Agricultural Experiment Station. Published with the permission of the Director as Paper Number 249 of the Journal Series. Also read before the symposium on "The Relation of Soil Fertility to the Nutritive Value of Food Crops", Agricultural and Food Division, American Chemical Society, Chicago meeting, September 11, 1946. Received for publication April 12, 1947.

[2]Associates in Animal Industry (Nutrition), Associate in Agronomy, and Assistant in Animal Industry (Nutrition), respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 858.

Often calcium is the second limiting factor in pasture production. When needed, limestone tends to produce an herbage that is richer in calcium. This may not be due altogether to a greater uptake by the grasses, but rather to a change in the botanical composition of the flora. Clover and other legumes, which contain relatively large amounts of calcium, do not thrive on calcium-deficient soils. Liming encourages their growth so that they are able to crowd out some of the less desirable, calcium-poor grasses and weeds.

EXPERIMENTAL

In the spring of 1938, a cooperative experiment was inaugurated between the Agronomy and Animal Industry (Nutrition) Departments of the North Carolina Agricultural Experiment Station and the Tennessee Valley Authority. This experiment was undertaken (a) to determine the optimum amounts of limestone and phosphate for a mountain pasture, (b) to compare the effectiveness of three of the more concentrated types of phosphatic fertilizers, and (c) to ascertain the changes in plant population and the chemical composition of the herbage produced by these fertilizers.

Forty treatment combinations of limestone and three types of phosphatic fertilizers were applied to 1/200-acre plots in a randomized block design with three replications. The treatments consisted of all combinations of none, ½, 1, and 2 tons of dolomitic limestone per acre with 64, 96, and 128 pounds of P_2O_5 per acre. Calcium metaphosphate, triple superphosphate, and fused phosphate were each used on separate plots to supply the various levels of P_2O_5. A set of all levels of limestone with no phosphate treatments was also included.

The plots were laid out and the treatments were applied on an old pasture sod in Haywood County, N. C. This sod was on Halewood loam, a typical soil of the Blue Ridge-Smoky Mountain area. At the beginning, all plots were seeded with a mixture of Kentucky bluegrass and white clover. Both the seed and the fertilizers were applied with as little disturbance of the old sod as possible, since many pastures similar to this are on slopes that are too steep to be cultivated without creating a serious erosion problem. The phosphate treatments were repeated in 1941 and again in 1944, i.e., at 3-year intervals, but no second application of limestone was made.

At the start of this experiment (1938) the pH of the soil was 5.5. In 1943, pH measurements on the top 2 inches gave values for the check plots ranging from 5.5 to 5.9; for the plots receiving ½ ton of limestone, 5.9 to 6.3; for 1 ton of limestone, 6.3 to 6.6; and for 2 tons of limestone 6.8 and 7.0. At this time, quick tests for phosphates indicated that there was no movement of this nutrient below the top inch of the soil.

Twice each season, plant population counts were made by the use of the inclined point quadrat, the readings being taken at the same time each year. No samples of the herbage were taken during the first summer. In all subsequent years the plots were clipped six times at approximately monthly intervals from the latter part of April to late September. A power mower with pan attachment was used for the clipping. Samples were taken only from the center strip of each plot in order to avoid any border effect. At the end of each season, the clippings were composited in proportion to their dry weight and analyzed for moisture, nitrogen, calcium, and phosphorus.

Carotene determinations were made on some of the clippings. In this case, portions of the fresh herbage were put into cellophane bags which were packed in the field into an insulated box containing solid carbon dioxide. The samples were then shipped to the laboratory, where they were kept frozen until analyzed.

RESULTS

The results reported here are summaries of observations taken over a period of 6 years, 1939 to 1944, inclusive, from the same experimental plots.

PLANT POPULATION

Woodhouse (13) has described the changes in the botanical composition occurring in the first 3 years as a result of the fertilizer treatments. More recently, he has summarized the June population counts through 1943 (14). Fig. 1 is a combination of charts V and VII of this publication.

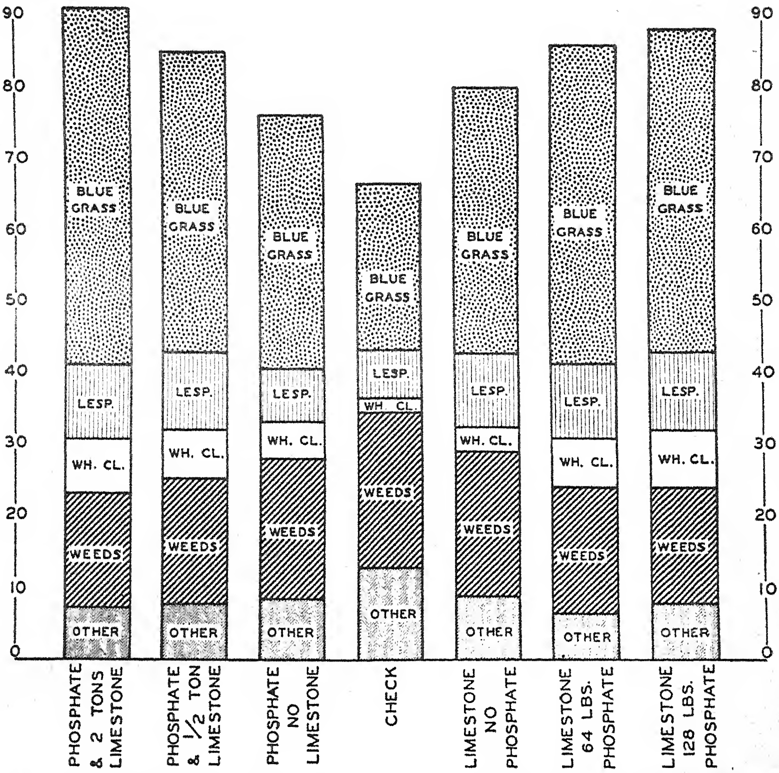

FIG. 1.—The average effect of the application of limestone and phosphate on the percentage cover and on the plant population of a mixed pasture sod.

This figure shows that both limestone and phosphate stimulated the growth of bluegrass, while lespedeza responded more to the limestone. White clover was more responsive to the phosphate. The percentages of other grasses and of weeds were depressed as the more desirable species increased. Fig. 1 also shows that there was little difference in plant population due to rates of phosphate in excess of 64 pounds per acre or in changing from 1 to 2 tons of limestone per acre.

PHOSPHATE CARRIERS

When this experiment was started, there was little information extant on the availability of the phosphate in the three concentrated

sources of phosphate. For this reason, all applications were made on the basis of total, rather than available, phosphate. The results have not indicated any differences in the availability of the phosphate in these three carriers.

For all practical purposes, the three materials have given essentially the same results. The yields of dry matter from plots receiving triple superphosphate have been slightly less than from comparable plots with either of the other forms, but the differences have had little statistical significance. The fused phosphate produced somewhat smaller increases in the phosphorus content of the plants but was slightly more effective in increasing the calcium content. This difference was not pronounced in any season and was not consistent over all the years. In view of the small differences found between these three types of phosphatic fertilizers, only the results from the fused phosphate will be considered in the remaining portions of this paper.

CAROTENE

Seven of the monthly clippings taken over a period of 4 years were analyzed for carotene. The averages are given in Table 1. There was considerable variation in the carotene content of the herbage from any given plot, depending partially upon the time of year that the samples were taken but primarily upon moisture conditions. When there was ample rainfall and the plants were growing vigorously, the carotene content was appreciably higher than after a prolonged dry period when the herbage was making little or no growth.

TABLE 1.—*Effect of the application of various combinations of fused phosphate and dolomitic limestone to the soil on the carotene content of the fresh herbage.**

P_2O_5, lbs. per acre	Carotene, mgs per 100 grams dry matter, with limestone, tons per acre				
	0	½	1	2	Mean
0	19.6	23.7	24.3	26.1	23.4
64	21.2	23.8	25.2	25.6	24.0
96	20.5	24.0	23.5	24.4	23.0
128	21.5	23.8	24.6	24.3	23.6
Mean...	20.7	23.8	24.4	25.1	23.5

*The values are averages for seven cuttings taken over a period of 4 years.

The marginal means (Table 1) show that the phosphate had practically no effect on the average amount of carotene in the herbage. Limestone tended to increase the carotene content. This effect was highly significant when the plants were growing well; but, in dry periods, it was not significant. Since the limestone had a relatively greater effect in changing the plant population than it had in increasing the carotene content of the herbage, the increase in carotene may well have been due to a change in botanical composition rather than to an increased synthesis by any one species. This is in accord with the conclusion of Maynard and Beeson (9), who say, "In general the carotene content and vitamin A potency of plant tissues have not

been found to be consistently influenced by the different fertilizers tried. The effect observed in the case of pasture is susceptible of other interpretation."

So far as these results are concerned, the question is of academic rather than of practical interest. Even the lowest value found at any time or from any plot was well above the maximum requirements of a grazing animal, provided it ate enough of the vegetation to supply its energy needs.

YIELDS OF DRY MATTER

The yields of dry matter on an oven-dry basis expressed as pounds per acre have varied quite markedly from year to year, depending primarily upon the amount and distribution of rainfall (c.f. Fig. 10). Fig. 2 shows graphically the effect of the fertilizer treatments in the years when the smallest (1941) and the largest (1943) yields were obtained. The season was very dry in 1941, while in 1943 conditions were generally favorable, particularly so for the growth of white clover.

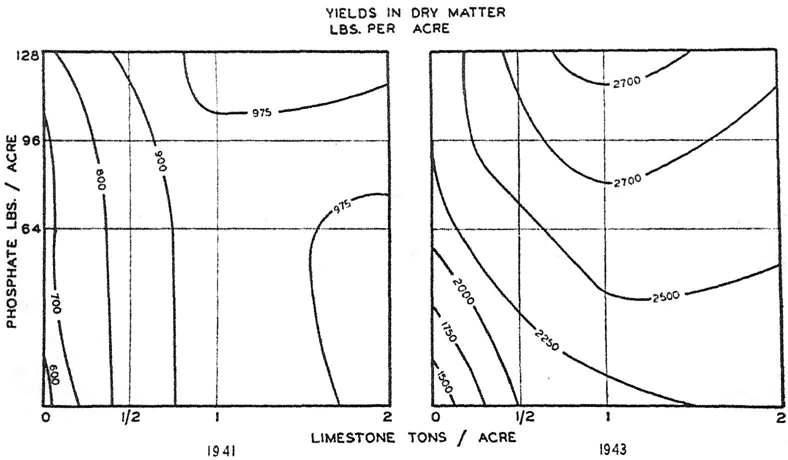

FIG. 2.—The effects of phosphate and limestone on the yields of dry matter, in pounds per acre, in a season of low rainfall (1941) and in a good growing season (1943).

The contour lines in Fig. 2, as well as those in Figs. 4, 6, and 8, have been interpolated between the observed values for the treatment combinations, which are represented by the intersections of the co-ordinates. Horizontal contours, parallel to the limestone levels, indicate a response to phosphate but not to limestone. Similarly, vertical contours show an effect of limestone but not of phosphate. When both are effective, the contours run diagonally across the chart. The magnitude of the response is indicated by the spacing between the contours, the closer the spacing, the greater the response. Figs. 2, 4, 6, and 8 are topographic maps of the upper surfaces of three dimensional drawings similar to those in Figs. 3, 5, 7, and 9.

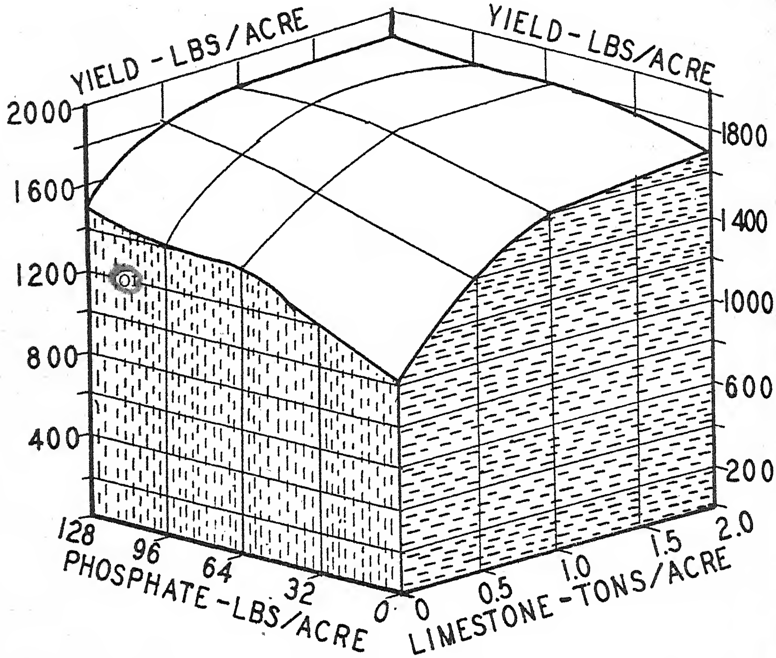

FIG. 3.—Average yields of dry matter, in pounds per acre, over a 6-year period in response to the application of limestone and phosphate.

In the dry season of 1941, not only were the yields lower, but the responses to the treatments were different from those in the most

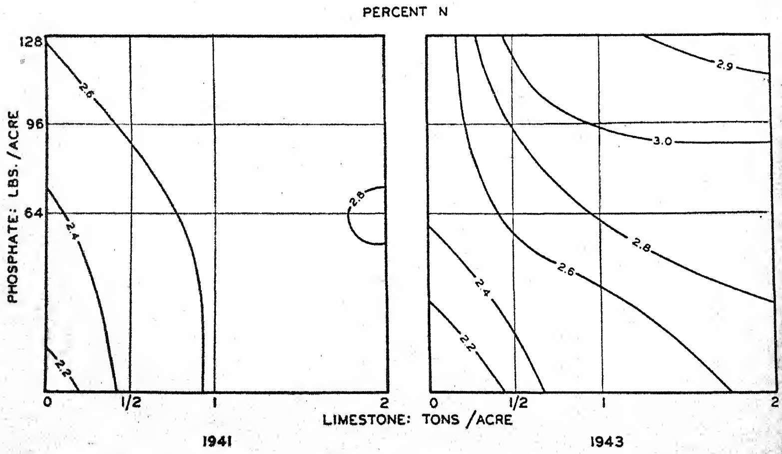

FIG. 4.—Variations in the percentage of nitrogen in the dry herbage from a mixed pasture sod with different combinations of limestone and phosphatic fertilizer in 1941, a season of low rainfall, and in 1943, a good growing season.

favorable season (1943). In the former year, phosphates had little effect, whereas the limestone increased the yields significantly. In the latter, both phosphate and limestone were highly effective in stimulating the growth of the herbage.

The average effects of the fertilizer treatments over a period of 6 years are shown in Fig. 3. The general picture is very similar to that of 1943, except that the magnitude of the yields is intermediate between the two extremes depicted in Fig. 2. Limestone markedly increased the yields in each of the 6 years, but phosphate was effective in only 4 of them. No indication of a significant limestone-phosphate interaction was found at any time, showing that these two agents exert their influence independently of each other.

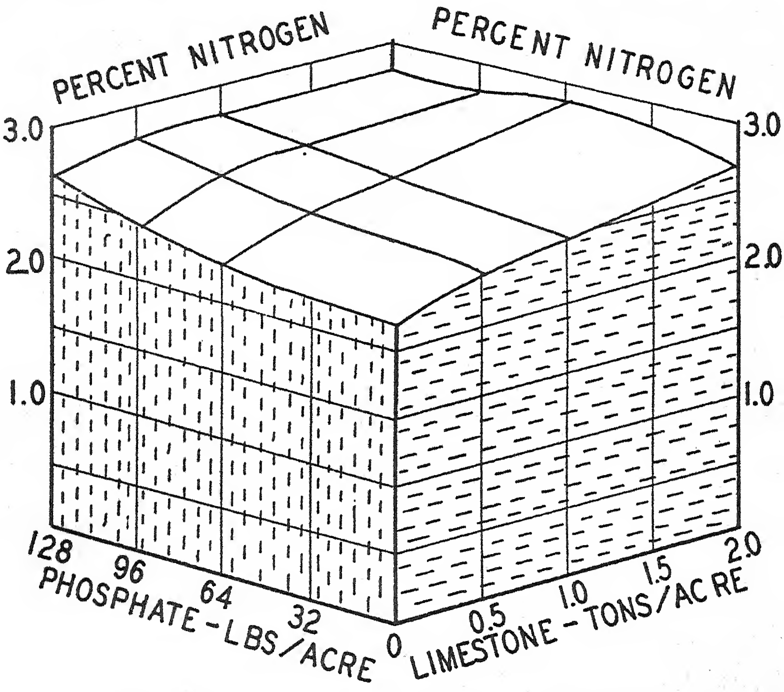

FIG. 5.—Mean effects of phosphate and limestone on the percentage of nitrogen in the herbage of a mixed pasture. Average of 6 years' observations.

NITROGEN CONTENT

The percentages of nitrogen in the composited clippings obtained in the driest (1941) and the most favorable (1943) growing seasons are shown in Fig. 4, while Fig. 5 presents the averages for the 6 years. When Figs. 2 and 4 or 3 and 5 are compared, it is seen that, in general, the percentage of nitrogen in the herbage follows the yields of dry matter. Both yields and nitrogen content respond in a similar manner to fertilizer treatments. In 1941, when the limestone affected the yields but the phosphate did not, the same relation held in respect to

the percentage of nitrogen. In 1943, and for the average of all years, both phosphate and limestone increased the percentage of nitrogen as well as the yields.

The fertilizer combination which gave the maximum yields of dry matter usually was not the one that produced herbage containing the highest amount of nitrogen. The optimum combination for these two criteria of effectiveness varied somewhat from year to year; but, on the average, maximum yields were obtained from 1 ton of limestone and either 96 or 128 pounds of P_2O_5 per acre, whereas 2 tons of limestone and 64 pounds of P_2O_5 per acre were the best for producing nitrogen-rich vegetation.

CALCIUM CONTENT

Neither phosphate nor limestone affected the calcium content of the herbage in the first two years of this experiment; however, after the second application of phosphate in 1941, and in all subsequent years, this fertilizer significantly increased the percentage of calcium. The effect of limestone on the calcium content was significant in 1942 only.

Contour graphs for each year show quite variable patterns. Those from the years in which minimum and maximum yields were obtained, Fig. 6, do not differ from each other as much as they do from those representing some of the other years. They both show that the limestone had little effect on the calcium percentage.

In general, as shown by the 6-year averages in Fig. 7, the calcium content of the herbage increased with increasing amounts of phosphate except when 2 tons of limestone were applied. In this case, the phosphate had little effect on the percentage of calcium.

Increasing levels of limestone tended to produce herbage containing somewhat more calcium when no phosphates were applied. With

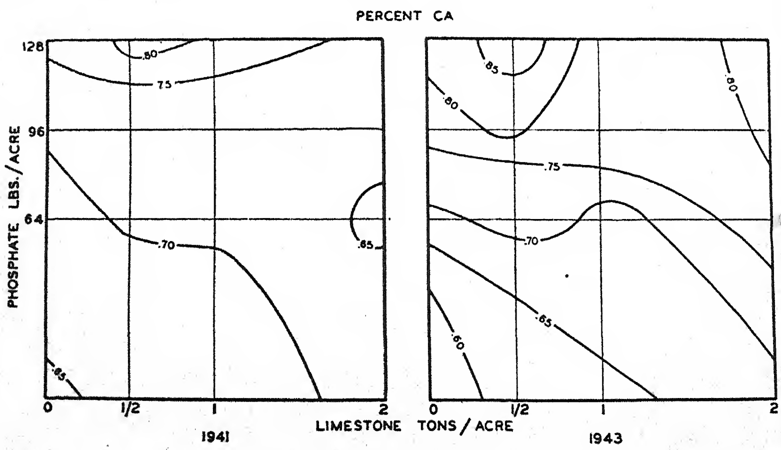

FIG. 6.—The effect of different combinations of limestone and phosphate on the percentage of calcium in pasture-herbage in a season of low rainfall (1941) (1941) and in a good growing season (1943).

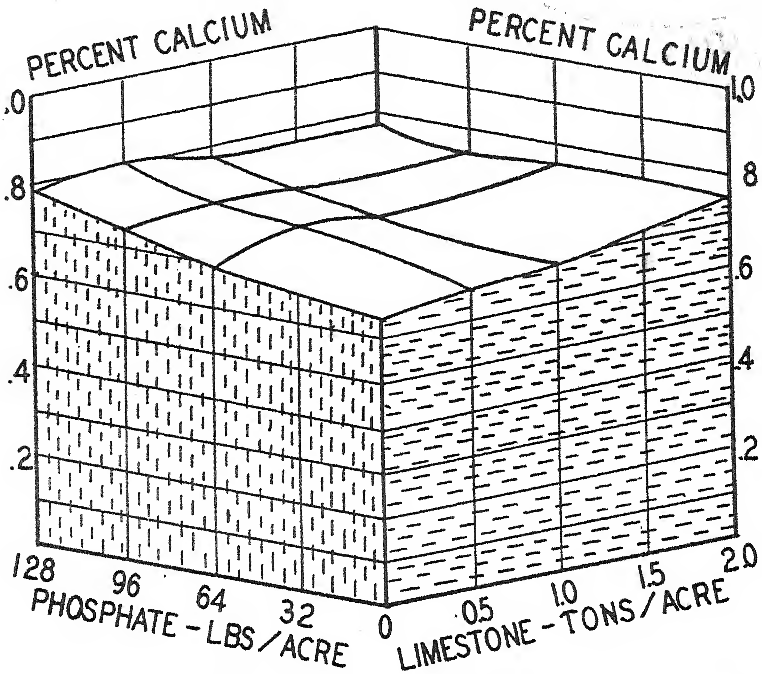

FIG. 7.—Average of 6 years' observations on the changes in the calcium content of the dry yields from pasture plots associated with the different limestone and phosphate treatments.

64 pounds of phosphate per acre, the effect was less marked. Limestone had practically no effect on the calcium content when 96 pounds of P_2O_5 per acre were applied. The maximum percentage calcium was found in the herbage from those plots that received 128 pounds of P_2O_5 and ½ ton limestone per acre.

PHOSPHORUS CONTENT

There has been little yearly variation in the effect of fertilizer treatments on the percentage of phosphorus in the herbage. In all years, including 1941 and 1943, as shown in Fig. 8, and as an average, Fig. 9, the phosphate has significantly increased the phosphorus content and the limestone has had practically no effect. There has been a tendency for the vegetation from the plots treated with the highest level of phosphate and none or ½ ton limestone per acre to contain somewhat larger amounts of phosphorus than that from plots getting the same amount of P_2O_5 but larger amounts of limestone.

TRENDS

TIME TRENDS

The yields of dry matter and the percentages of N, Ca, and P for the untreated controls and for the average of all treatments in each of the 6 years are shown in Fig. 10.

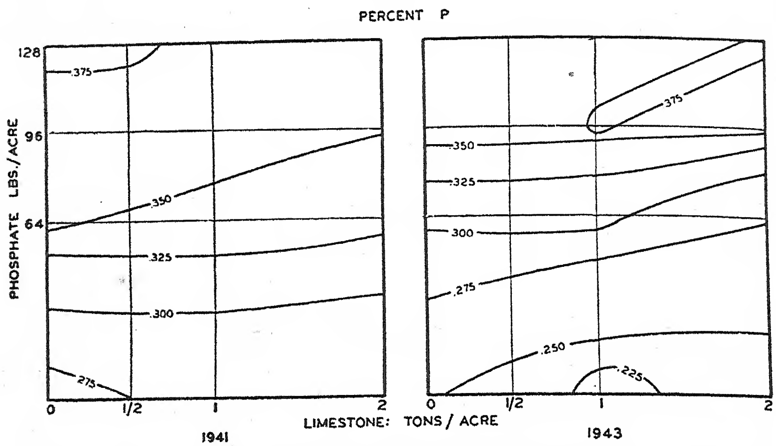

FIG. 8.—The effects of phosphate and limestone on the percentage of phosphorus in pasture herbage in a dry year (1941) and in a good growing season (1943).

There is no indication of a trend with time toward either larger or smaller yields. On the other hand, both the percentages of N and of Ca have shown a downward trend throughout the course of this

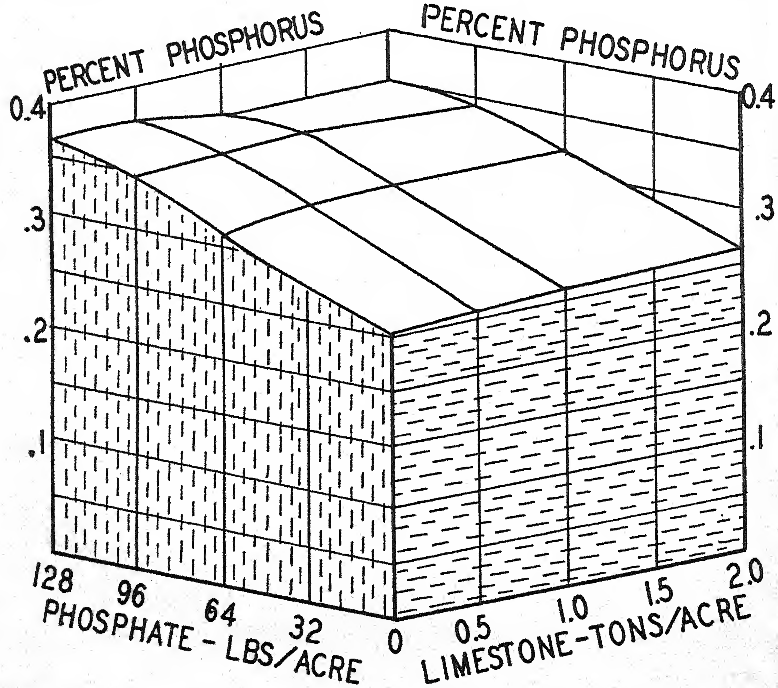

FIG. 9.—Mean effects of phosphate and limestone on the percentage of phosphorus in pasture herbage. Average of 6 years' observations.

experiment; however, the downward trend in N is not very pronounced. In general, this trend has not fluctuated with the variations in meteorological conditions which have had such a pronounced effect on the yields, although Figs. 11 and 12 show that there may be an association between the yields and the percentages of these nutrients. The decline in the N and Ca content of the herbage was equally as pronounced whether it was grown on the control plots or on those fertilized with any of the treatment combinations. There has not been a concomitant change in the botanical composition of the herbage that can explain this trend.

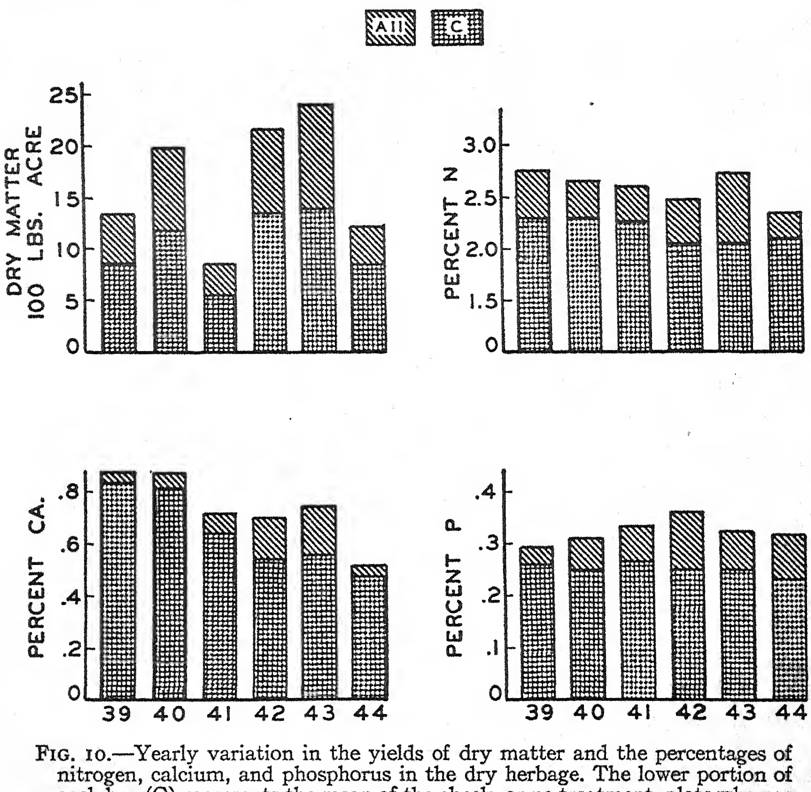

FIG. 10.—Yearly variation in the yields of dry matter and the percentages of nitrogen, calcium, and phosphorus in the dry herbage. The lower portion of each bar (C) represents the mean of the check, or no treatment, plots whereas the entire bar shows the mean of all treatments, including the checks.

In contrast to the decline in the percentages of N and Ca, the P content of the herbage from those plots which were not phosphated has remained rather constant throughout the 6 years, whereas there has been a small upward trend where phosphate was applied.

In spite of the trends shown in the percentages of N and Ca, it is unsafe to extrapolate very far into the future. Any one of the numerous factors that condition the N or Ca content of this mixed pasture herbage may so change as to alter the picture at any time. It is pos-

sible that, without essential change in these factors, an equilibrium will be reached and the N and Ca contents become stable. Certainly the level of these nutrients in the plants cannot fall off indefinitely, since there is some minimum below which the vegetation cannot live.

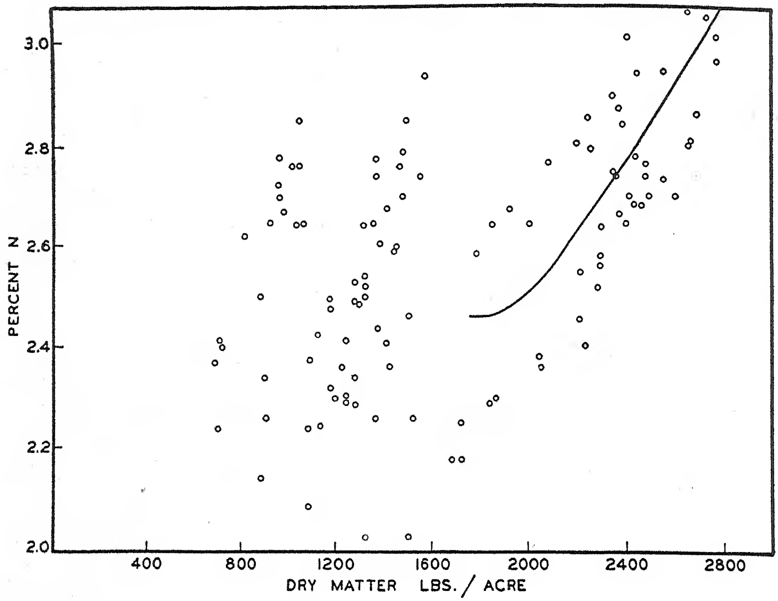

FIG. 11.—Scatter diagram showing the relation between yields of dry matter and percentage of nitrogen in pasture herbage. The observations were made over a period of 6 years.

If the observed trends were solely dependent upon the available nutrients in the soil, there should have been a differential between results from the fertilized and the unfertilized plots. No nitrogenous fertilizer has been used so that the decrease in the N content of the herbage from the control plots might be attributed to a diminution of the available N in the soil. This, however, cannot explain the same trend from the fertilized plots. It would be contrary to usual experience to postulate that available soil nitrogen has been depleted as rapidly from soils on which clover and legumes are flourishing as from those supporting a much smaller growth of these legumes. It does not seem probable that the downward trend in N and Ca was due to gradual exhaustion of available soil Ca. In the first place, liming had practically no effect on the percentage Ca in the herbage; and, secondly, there was no difference in the trends of the percentages of either N or Ca, depending upon whether the plots were limed or not, and the phosphorus content, which was more responsive to liming, has not declined. There is no indication in the yield data, in the population counts, or in the phosphorus content of the herbage that available Ca is being decreased.

In another experiment on an adjoining field it has been found that potash is not a limiting factor in this soil. It would seem that some factor, or factors, other than the availability of the plant macronutrients in the soil, and the differences in plant populations, is responsible for the downward trend in the nitrogen and Ca content of the herbage.

ASSOCIATION OF YIELD WITH COMPOSITION

It is known that if the soil contains more than sufficient nutrients to meet the needs of a plant for growth, and if other conditions are favorable, the plant will store extra amounts of Ca, P, K, N, or other elements in its tissues. Since this extra accumulation, or luxury consumption, may be significant with respect to the nutritive status of animals, it seemed of interest to inquire into the relation between yield and the percentages of N, Ca, and P found in this experiment. To this end, the yield of dry matter from each treatment combination for each year is plotted against its N, Ca, and P content in Figs. 11, 12, and 13, respectively. Free hand trend lines have been drawn in these figures.

With yields less than 2,000 pounds of dry matter per acre, there is a very wide scatter in the points in Fig. 11, and no apparent correlation between yield and N percentage. When yields were greater than

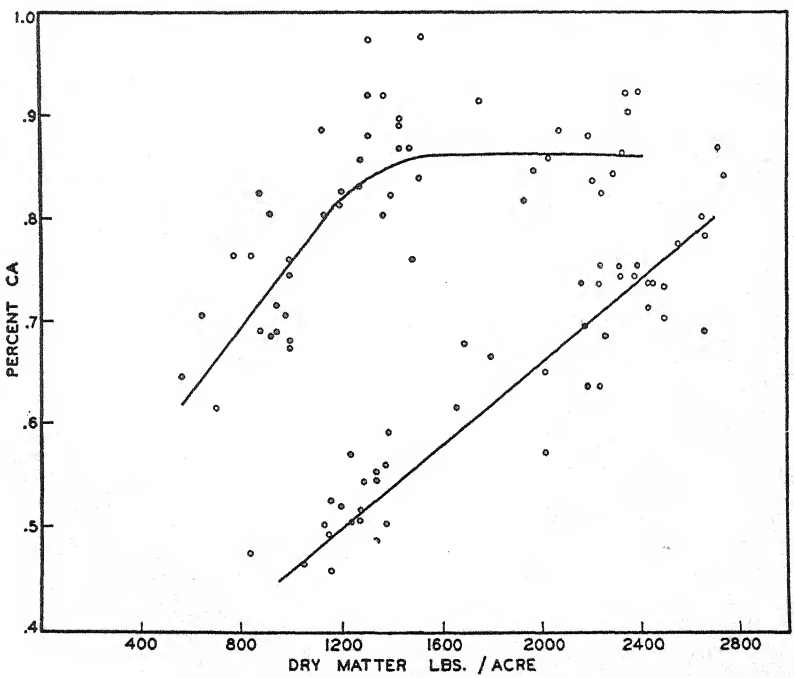

FIG. 12.—Scatter diagram showing that the relation between yields of dry matter and their calcium content was different in the first 3 years (upper curve) from that in the last 3 years (lower curve).

2,000 pounds, there was a tendency for the larger yields to contain more N. There is not enough evidence to decide if this is true luxury consumption. It may well be that the larger percentages of N are the result of more metabolic tissue in the plants which made the greater growth and do not represent excess storage.

When the Ca percentages were plotted against the yields, as in Fig. 12, the data divided into two distinct groups. The points associated with the upper curved line were all from the first 3 years' results, while the data from the last 3 years followed a distinctly different trend. In the latter group, there was a smaller percentage of Ca per unit of herbage produced than in the first group. There is a distinct linear tendency for the larger yields to contain a greater percentage of Ca.

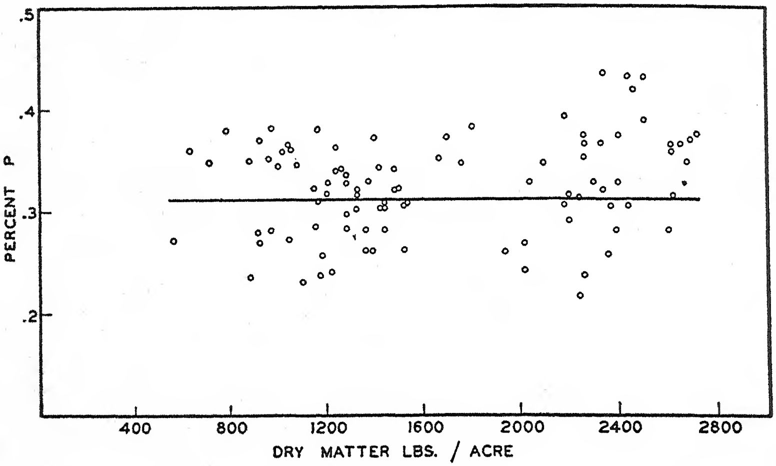

FIG. 13.—Scatter diagram indicating that there was no correlation between yields of dry matter and percentages of phosphorus in the 6 years of this experiment.

The picture for the first 3 years is quite different. The percentage of Ca in the herbage increased with the yield up to a moderate yield of about 1,400 pounds per acre. Above this amount there does not seem to be any relation with the Ca content. Since the points at the left and lower end of this curve are chiefly from the 1941 data, when yields were low on account of drought, it may be seen that in the first two years of the experiment the Ca content of the herbage was not correlated with the yields to any significant extent.

Evidently something happened during the course of this experiment to change the Ca relationships. What this was is not clear. There is no apparent evidence that it affected the yields, the plant populations, or the N or P content of the herbage. Perhaps it is related in some way with the second application of phosphate in 1941. If so, there was either a lag of 1 year between the application and its effect becoming apparent, or the poor growth in this dry season masked an effect that otherwise would have been manifest. In the

discussion of Fig. 7, it was mentioned that the phosphate treatments did not affect the Ca content of the herbage in the first 2 years but caused an increase thereafter.

The scatter diagram in Fig. 13 shows that the P percentage is independent of the yields. This is contrary to expectation because other investigators have found considerable excess storage of P, and with the higher rate of phosphate application there should have been an excess of available P in the soil.

NUTRITIONAL SIGNIFICANCE

QUANTITATIVE

Insofar as chemical analyses are able to serve as criteria, the necessary data for judging the nutritional adequacy of these samples of pasture herbage, in respect to protein, Ca, and P, are given in Tables 2 and 3. Table 2 sets forth the minimum average amount of digestible protein, Ca, and P found in the cuttings for any year throughout the series. The results for only 4 of the 16 treatments are presented. Those omitted were all higher than those from the check plots and some were higher than any of the results shown. These minimum figures, regardless of the year in which they were obtained, have been selected for the sake of conservatism in the discussion which follows.

TABLE 2.—*Minimum average amounts of digestible protein, calcium, and phosphorus found in the clippings for any year from 4 of the 16 fertilizer and lime treatments.*

Treatment		Digestible protein, %*	Ca, %	P, %
Phosphate, lbs. per acre	Limestone, tons per acre			
None	None	7.5	0.47	0.23
None	2	9.3	0.50	0.24
128	None	8.7	0.55	0.32
128	2	9.5	0.51	0.30

*Based on the assumption that 60% of the crude protein (N × 6.25) is digestible.

TABLE 3.—*Recommended allowances for beef and dairy cattle.*

	Weight, lbs.	T.D.N., lbs. per day	Digestible protein, %	Ca, %	P, %
Beef Cattle*					
Normal growth, heifers and steers	400	7.0	7.5	0.37	0.28
Bulls, growth and maintenance...	600	10.0	8.1	0.33	0.25
Cows, nursing calves............	900–1,100	14.0	5.0	0.24	0.18
Dairy Cattle†					
Growth........................	600	8.5	5.0	0.19	0.16
Maintenance....................	1,400	11.0	3.7	0.14	0.17
Pregnant, last 6–12 weeks.......	1,500	14.0	5.8	0.17	0.13

*From Guilbert, *et al.* (6).
†Computed from Loosli, *et al.* (8), assuming that T.D.N. constitutes 50% of the total dry matter.

The data presented in Table 3 have been taken from reports III and IV of the Committee on Animal Nutrition of the National Research Council (6, 8). These figures relate chiefly to ages and physiological condition where the nutritive requirements are at a maximum. Hence, any conclusion based on a comparison between the data in these two tables will be very conservative. Such a comparison shows that there is ample calcium present in the herbage from any or all treatments to meet the needs of either dairy or beef cattle.

The minimum protein in the vegetation from the check plots was not quite optimum for young growing bulls, but was adequate for all other classes. The herbage from all other treatment plots contained sufficient protein to meet the needs of all cattle.

When phosphates were applied to this pasture, the herbage contained enough P to meet the needs of all ages of cattle. Without phosphatic fertilizers, the forage did not contain an optimal level of P for young growing beef calves. It was sufficient, however, for the dairy breeds and not so low as to cause deficiency symptoms in the others.

QUALITATIVE

The above conclusions are based on the assumption that the nutrients in these grasses are at least as available as the averages from which the requirements were derived.

Albrecht (1, 11) has championed the idea that the nutrients, particularly protein, in plants grown on soils deficient in plant food are inferior to those contained in well-nourished plants. In his opinion, this inferiority is due both to a smaller content of the nutrient in the plant and to a lessened availability to the animal and, in the case of protein, to a poorer quality.

Williams, McLeod, and Morrell (12) claim that the phosphorus in a low-phosphorus hay is not as available to rats as that in a high-phosphorus hay. These investigators have not worked with cattle. None of the reviews or texts on the nutritive requirements of cattle or on the nutrient content of feeds and forages that have come to the attention of the authors contain any hint that the digestibility or availability of the nutrients in a feed varies directly with the plant nutrients in the soil.

Few digestion trials or other critical comparisons between the nutritive values of pasture grasses from fertilized and unfertilized soils have been made. Crampton and Jackson (4) state that the digestibility of mixed pasture herbage appears to follow closely the leaf-stem ratio. They conclude that their data offer strong evidence toward refuting the claim that fertilizer treatments to pastures resulting in increased protein correspondingly increases the nutritive value of such pastures when the lowest level of protein is above the needs of steers or sheep. They also conclude that neither an increase in protein nor a decrease in crude fiber is a true index of improvement in nutritive value (digestible energy).

Eheart and Pratt (5) conducted a series of digestion and balance trials with dairy cows to determine if fertilization of bluegrass pasture affects the digestibility and utilization of its constituents as well as the quality and quantity of the resulting milk. They found statis-

tically significant differences in the amounts and the digestibility of several constituents of the herbage. The grass from the unfertilized pasture contained more materials yielding energy, while the fertilized herbage was richer in digestible protein and minerals. There were sufficient nutrients present in either to meet the needs of the cows and the differences were not great enough to affect milk production. They conclude that there was no practical difference in the nutritive value of the fertilized and unfertilized herbage.

SUMMARY AND CONCLUSIONS

Observations were made over a period of 6 years of a series of plots on a mixed pasture sod top-dressed without incorporation with various combinations of dolomitic limestone and fused phosphate. The more desirable pasture plants, Kentucky bluegrass, white clover, and lespedeza, increased and the weeds decreased as a result of the use of either of these fertilizing agents.

Either or both of the treatments increased the yields of dry matter and the percentage of nitrogen in the dry matter. None of the treatment combinations changed the carotene content to a significant extent. The application of phosphate to the soil increased the percentage of Ca in the herbage in the last 4 years of the experiment but not in the first 2, and the limestone had little effect on the Ca content.

The P content of the vegetation was little affected by the limestone, but was increased when phosphatic fertilizers were applied.

The percentages of N and Ca have decreased steadily during the 6 years of observations, but the P percentage has remained relatively constant. The yields of dry matter have been very responsive to meteorological conditions and have not exhibited any time trends either upwards or downwards.

There has been no definite evidence of luxury consumption of N, Ca, or P. The percentages of N and Ca in the dry matter have been higher when greater yields were obtained, but this may have been due to an increase in metabolic tissue in the more vigorously growing vegetation rather than to an excess storage. The P content of the herbage was virtually independent of the yields.

It is concluded that the herbage from any of these plots, including the unfertilized controls, probably contained enough macronutrients, except P, to meet the needs of cattle, provided that it be eaten in sufficient amount to supply the energy requirement. The P was adequate in the vegetation from all plots that received phosphatic fertilization but was suboptimum for growing beef calves in the forage from the nonphosphated plots.

The effects of the fertilizer treatments on the composition of the herbage has varied from year to year, and there has been a downward trend in the Ca and P content over the experimental period. The relation between the total yield of dry matter and its Ca content changed rather abruptly after the third year, and there has been little evidence of luxury consumption by these plants. While the causes of these results are largely unexplained, they are undoubtedly the resultant of the interaction of many chemical, physical, and biological

forces. Until our knowledge of these forces and their interrelationships is much more complete, it seems unsafe to draw sweeping conclusions in respect to the effect of fertilization on the nutritive value of plants.

LITERATURE CITED

1. ALBRECHT, WM. A. Soil fertility and the human species. Chem. and Eng. News, 21:221–227. 1942.
2. BEESON, KENNETH C. The mineral composition of crops with particular reference to the soils in which they were grown. U.S.D.A. Misc. Pub. 369. 1941.
3. BROWNE, C. A. Some relationships of soil to plant to animal nutrition. The major elements. U.S.D.A. Yearbook, 1938:777–806. 1938.
4. CRAMPTON, E. W., and JACKSON, I. R. C. Seasonal variation in chemical composition of pasture herbage and the relation to its digestibility by steers and sheep. (Pasture Studies XXVI.) Jour. Animal Sci., 3:333–339. 1944.
5. EHEART, JAMES F., and PRATT, AVERY D. The digestibility and utilization by dairy cows of nutrients from fertilized and unfertilized bluegrass pasture. Va. Agr. Exp. Sta. Tech. Bul. 81, 1942.
6. GUILBERT, H. R., GERLAUGH, PAUL, and MADSEN, L. L. Recommended nutrient allowance for beef cattle. Committee on Animal Nutrition, Nat. Res. Council, Report IV. 1945.
7. KRAUS, E. J. Sources and cycles of the nutritive elements. U.S.D.A. Yearbook, 1939:405–417. 1939.
8. LOOSLI, J. K., HUFFMAN, C. F., PETERSON, W. E., and PHILLIPS, P. H. Recommended nutrient allowances for dairy cattle. Committee on Animal Nutrition, Nat. Res. Council, Report III. 1945.
9. MAYNARD, L. A., and BEESON, K. C. Some causes of variation in the vitamin content of plants grown for food. Nutr. Abs. and Rev., 13: 155–164. 1944.
10. RUSSELL, F. C. Minerals in pasture deficiencies and excesses in relation to animal health. Imp. Bur. Animal Nutr., Tech. Communication 15. 1944.
11. SMITH, G. E., and ALBRECHT, WM. A. Feed efficiency in terms of biological assays of soil treatments. Soil Sci. Soc. Amer. Proc., 7:322–330. 1943.
12. WILLIAMS, D. E., MCLEOD, F. L., and MORRELL, E. Availability to rats of phosphorus in red clover hays of widely varying phosphorus content. Jour. Nutr., 23:501–511. 1942.
13. WOODHOUSE, W. W., JR. Some effects of fertilization on the botanical and chemical composition of pastures. Proc. Assoc. Southern Agr. Workers, 42:41–42. 1941.
14. ————. Use of TVA phosphates and limestone on permanent pastures. N. C. Agr. Exp. Sta. Agronomy Information Circ., 140. 1945.

Influence of Placement on Response of Crops to Calcium Phosphates[1]

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AMMONIATED superphosphates, especially those containing more than 3% ammonia, have not always proved as efficient as nonammoniated superphosphate in promoting crop growth (1, 10, 11).[5] Several factors are known that affect the relative efficiency of the ammoniated material and more recently evidence was obtained by Ross, *et al.* (7) that the response of crops to ammoniated superphosphate was differently affected by varying placement than was the response to nonammoniated superphosphate.

Monocalcium phosphate, a water-soluble salt, is the principal phosphatic component of superphosphate, but ammoniated superphosphate also contains other calcium phosphates having different solubilities that are present in proportions that depend upon the conditions and extent of the ammoniation (5). These are di- and tricalcium phosphates, hydroxylapatite, and perhaps fluorapatite (6). Another calcium phosphate of interest in connection with fertilizers is silicocarnotite, the active phosphatic component of basic slag (2). Crop response to some of these phosphates has been studied (1, 4, 8), but very little attention has been paid to the factor of placement. It appeared desirable, therefore, to investigate the effect of varying placement on the response of crops to these phosphorus compounds under the controlled conditions possible in the greenhouse. This paper presents the results of such a study. A brief preliminary report on a portion of the data has been made elsewhere (3).

PROCEDURE

The same experiment, uniform except for crop and soil variations, was conducted at Fayetteville, Ark.; Auburn, Ala.; and Beltsville, Md. This experiment, with some modifications, was repeated twice at Beltsville where various supplementary tests were also conducted.

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[1]Contribution from the Division of Soils, Fertilizers, and Irrigation, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md., in cooperation with the Alabama and Arkansas experiment stations. Part of this material was presented as Paper No. 6, of the Division of Fertilizer Chemistry of the American Chemical Society, Chicago, September 9, 1946. Received for publication June 14, 1947.

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[5]Numbers in parenthesis refer to "Literature Cited", p. 868.

The placements were characterized by the degree to which the phosphate was mixed with the soil and by the restriction of variation in placement to the phosphates only. The nitrogen and potash carriers, except for a special test, were always distributed through all the soil in the pot. Any effect of placement was thus due to variation in the location of the phosphate. A placement affording the least possible mixing of soil and phosphate consisted of a band 0.5 inch wide forming a circle 6 inches in diameter. In other placements the phosphate was mixed with 2.5, 10, 40, 60, or 100% of the soil in the pot and the mixture placed in a layer extending downward from the seed level. The seeds were placed in a 6-inch circle on top of this layer or directly in the band in contact with the phosphate. In some of the tests, the band was located 0.75 inch below the seed. The two bands will be referred as the "contact band" and the "band below", respectively.

The phosphates were applied to each soil (except as noted) at a total P_2O_5 rate, different for each soil, shown by preliminary experiments to give a crop response well below the maximum attainable with larger phosphate applications. This will be called the "standard rate." The nitrogen and potash carriers, however, were always applied in amounts more than adequate to meet the needs of the crop for these elements. The conventional acre weight of 2,000,000 pounds was assumed in all calculations.

The pots, of the 2-gallon glazed, straight-sided variety with side vent, 8.5 inches inside diameter, were placed in random positions on the bench or randomized within blocks. Three replicates were used except where otherwise noted. The plants were thinned when still very small to a number, according to the crop, that avoided undue crowding during growth. The cultures were kept adequately moist at all times with periodic readjustment to the initial weight through the addition of water. No water was allowed to drain off.

The experiments conducted in accordance with the main design consisted of a crop of Sudan grass on the Newtonia soil and one on the Sassafras soil, three wheat crops also on the Sassafras, and a crop of oats on the Cecil soil. All were normal healthy crops except the oats which were stunted and small due to red spider damage and other difficulties. The crops were harvested at, or near, maturity and dry weights of the aerial portions recorded.

All data except those for the oats were interpreted with the aid of analyses of variance coupled with the examination of such individual degrees of freedom as were of interest. The individual pot yields were not reported for the oats. The statistical examination was routine and details will not be reported except where they serve to emphasize or evaluate some particular point. Variations in the data not statistically significant at the conventional 19:1 odds are ignored except as noted.

SOILS AND PHOSPHATES

The soils used, with their main physical and chemical characteristics, are listed in Table 1. All are low in available phosphorus as judged by the various criteria shown in the table.

The phosphates are listed in Table 2, with pertinent data on their analysis, preparation, and other features. The particle size of the monocalcium phosphate was such that it all passed a number 20 U. S. standard sieve. The di- and tricalcium phosphates and hydroxylapatite passed the number 80 sieve, the fluorapatite the number 200, and the silicocarnotite the number 100 sieve. All the phosphates were specially prepared in pure form except the fluorapatite. The latter is the major phosphatic component of Tennessee brown-rock phosphate and was used in that form. The fluorapatite of phosphate rock is microcrystalline. Macrocrystalline fluorapatite would probably be even less available.

RESULTS

The yields are summarized in Table 3. In general, the differences obtained were large, making interpretation of the results relatively easy. This is illustrated in Table 4 by the high significance (odds 999:1) attained by the main factors and their interaction. Many of the individual degrees of freedom attained equally high significance. Table 5 shows the average relative yields (monocalcium phosphate

TABLE 1.—*Physical and chemical properties of the soils used in the experiments.**

Property	Soil name, texture, and location		
	Newtonia silt loam Fayetteville, Ark.	Cecil clay loam, Auburn, Ala.	Sassafras silt loam, Beltsville, Md.
Moisture equivalent, %	15.7	23.4	17.3
Silt, %	54.7	21.7	41.5
Clay, %	9.0	45.5	11.2
Organic matter, %	1.2	0.6	0.8
pH (saturated soil)	5.7	5.3	5.9
Exchangeable hydrogen, m.e. per 100 grams	1.53	2.73	0.94
Lime requirements, lbs. $CaCO_3$ per acre	1,500	2,700	900
Base exchange capacity, m.e. per 100 grams	3.8	3.82	4.1
Truog phosphorus, lbs. P_2O_5 per acre	33.9	7.3	21.1
Available phosphorus, Indiana quick test	Very low	Very low	Very low
Exchangeable phosphorus, lbs. P_2O_5 per acre (9)	570	400	280
Anion exchange-adsorption capacity, m. mols per 100 grams	2.9	8.1	0.86
Saturation of anion exchange capacity, %	13.7	3.5	23.3

*Physical constants and organic matter determined by L. T. Alexander; pH by M. S. Anderson; exchangeable hydrogen, lime requirement, and base exchange capacity by I. C. Brown; exchangeable phosphorus, anion exchangeable-adsorption capacity, and Truog phosphorus by M. G. Keyes and E. J. Rubins.

equals 100) based on two Sudan grass and two wheat crops. The oat data could not be critically evaluated and, although seeming to show

TABLE 2.—*Description of phosphates used in experiments.**

Name	Chemical formula	Analysis		P_2O_5/CaO		Citrate-soluble P_2O_5, %†
		CaO, %	P_2O_5, %	Found	Calculated	
Monocalcium phosphate[1]	$Ca(H_2PO_4)_2 \cdot 1\ H_2O$	22.30	55.81	2.505	2.533	100.0
Dicalcium phosphate[2]	$CaHPO_4$	40.74	51.58	1.265	1.266	100.0
Tricalcium phosphate[3]	$Ca_3(PO_4)_2 \cdot 2/3\ H_2O$	51.03	44.02	0.862	0.845	22.4
Hydroxylapatite[4]	$3Ca_3(PO_4)_2 \cdot Ca(OH)_2$	54.58	41.60	0.762	0.760	24.3
Fluorapatite	——[5]	.....	33.75	.....	.....	7.05
Silicocarnotite[6]	$Ca_3(PO_4)_2 \cdot Ca_2SiO_4$	57.95	28.98	0.508	0.506	95.9

*Analyzed and supplied or prepared by D. S. Reynolds, V. L. Gaddy, and W. L. Hill.

†Percentage of total P_2O_5, determined by the official method of the Association of Official Agricultural Chemists. (Methods of Analysis, Ed. 6. 1945, page 25.)

[1]Reagent grade recrystallized from concentrated phosphoric acid, washed with acetone, and air-dried.

[2]Reagent grade recrystallized by dissolving in dilute HCl and precipitating with dilute NH_4OH. Crystals were washed with alcohol and air-dried.

[3]Dicalcium phosphate, suspended in water at 100°C, was hydrolyzed by titration with dilute NH_4OH. The crystals were washed in cool water and air-dried.

[4]The freshly precipitated material obtained by reacting equal amounts of 0.5 M solutions of $(NH_4)_3PO_4$ and $Ca(NO_3)_2$ was autoclaved at 30 lbs. per sq. in. for six periods of 16 hours each with intervening changes of liquid. The product was air-dried.

[5]Used in the form of Tennessee brown-rock phosphate.

[6]A mixture of precipitated tricalcium phosphate, very fine crystobalite, and calcium carbonate in the required proportions was heated at temperatures of 900°, 1200°, 1400°, and finally 1600° C, with intervening grinding to 100 mesh until no gain in homogeneity (as judged by petrographic examination) resulted on further heating at 1600° C.

the same general trends, were omitted from the average. The third wheat crop (C) was not produced under comparable conditions and was also omitted. Use of these data will later be made in this paper.

In the band placement monocalcium phosphate was consistently the most efficient in producing crop response. The best of the other phosphates were on the average only about half as effective. In the 2.5% mixing this relation is very different. In this placement dicalcium phosphate and silicocarnotite were generally as efficient as monocalcium phosphate and sometimes produced significantly higher yields than the latter phosphate. This general relationship was maintained throughout all the placements where the phosphates were mixed with the soil. The average relative efficiencies of dicalcium phosphate and silicocarnotite were greater than that of monocalcium phosphate in all except the band placement.

Tricalcium phosphate produced significantly improved responses relative to the band placement, in some cases when mixed with a portion of the soil. These responses were sometimes not significantly different from those produced by monocalcium phosphate. On the average, however, it was not as efficient.

The average relative standings of the two apatites were low throughout and the response to these phosphates was comparatively little affected by placement. An exception may be noted in the 40% mixing with the Sudan grass on the Newtonia soil where both apatites produced yields not significantly different from those produced by monocalcium phosphate. This, however, is an isolated instance.

Yields from mono-, di-, and tricalcium phosphates and silicocarnotite tended to fall off when the phosphate was mixed with more than 40% of the soil. The apatites were less affected by mixing with a large proportion of the soil.

In a side experiment, which will not be described in detail, wheat was fertilized with superphosphate applied at several rates in the same series of placements. The effect of placement was very similar to that observed with monocalcium phosphate. There was little difference between the band and mixing with a limited proportion of the soil; either of these placements appeared optimum for superphosphate. The yields fell off as the proportion of soil mixed with the phosphate became large.

EFFECT OF HAVING PHOSPHATE IN CONTACT WITH SEED

It was suggested that low response to some of the phosphates in the contact band was due to some effect of the phosphates on the seed or young plants. In one of the experiments with wheat on the Sassafras soil (B, Table 3), both the contact band and a band below, located ¾ inch below the seed, were used. Yields obtained in these two placements did not differ significantly from each other with any of the phosphates. Contact between the seed and phosphate was thus not the explanation of the low yields from dicalcium phosphate and silicocarnotite obtained in band placements in this case.

To test this point further, a limited experiment was conducted in which wheat and Sudan grass were grown simultaneously on the Sassafras soil. Dicalcium phosphate, silicocarnotite, superphosphate,

TABLE 3.—*Average yields produced by various calcium phosphates applied in several placements in grams per pot of oven-dry tissue.*

Phosphates	Placements						
	Band below	Contact band	2½% mixing	10% mixing	40% mixing	60% mixing	100% mixing
Sudan Grass on Newtonia Silt Loam (Fayetteville, Ark.)							
Monocalcium phosphate....	—	20.7	22.3	22.8	16.0	—	12.8
Dicalcium phosphate.......	—	16.9	27.7	29.4	25.5	—	14.8
Tricalcium phosphate......	—	16.0	22.8	27.2	20.9	—	14.0
Hydroxylapatite...........	—	13.0	17.0	17.3	15.3	—	10.4
Fluorapatite*.............	—	9.3	12.2	15.6	16.1	—	8.3
Silicocarnotite...........	—	14.5	27.7	25.4	22.8	—	14.7
Oats on Cecil Clay Loam (Auburn, Ala.)							
Monocalcium phosphate....	—	4.20	3.70	2.70	1.33	—	1.03
Dicalcium phosphate.......	—	3.67	4.00	3.80	1.50	—	1.07
Tricalcium phosphate......	—	2.03	3.47	2.97	1.80	—	1.07
Hydroxylapatite...........	—	2.23	2.93	2.90	1.53	—	1.50
Fluorapatite*.............	—	1.20	1.33	1.53	1.37	—	0.83
Silicocarnotite...........	—	3.03	3.90	4.13	3.57	—	0.77
Sudan Grass on Sassafras Silt Loam (Beltsville, Md.)							
Monocalcium phosphate....	—	—	28.7	11.5	28.5	—	24.3
Dicalcium phosphate.......	—	—	40.3	22.8	28.0	—	21.8
Tricalcium phosphate......	—	—	18.5	11.2	9.5	—	8.3
Hydroxylapatite...........	—	—	7.7	3.2	4.8	—	6.3
Fluorapatite*.............	—	—	3.5	1.7	1.7	—	5.7
Silicocarnotite...........	—	—	43.3	36.7	24.3	—	21.2
Wheat on Sassafras Silt Loam (Beltsville, Md.)—A†							
Monocalcium phosphate....	—	40.2	39.3	37.3	29.3	—	32.3
Dicalcium phosphate.......	—	18.0	25.3	36.7	30.8	—	34.7
Tricalcium phosphate......	—	20.5	20.5	18.2	17.5	—	19.0
Hydroxylapatite...........	—	13.7	14.2	13.8	15.2	—	14.3
Fluorapatite*.............	—	14.2	13.0	12.3	11.7	—	12.3
Silicocarnotite...........	—	21.2	40.8	37.2	31.8	—	34.5
Wheat on Sassafras Silt Loam (Beltsville, Md.)—B†							
Monocalcium phosphate....	30.4	27.3	22.0	28.1	—	20.0	—
Dicalcium phosphate.......	8.3	10.5	24.5	19.1	—	25.4	—
Tricalcium phosphate......	12.4	12.8	15.7	14.9	—	8.3	—
Hydroxylapatite...........	5.5	4.9	4.5	5.5	—	4.9	—
Fluorapatite*.............	4.5	3.7	4.6	4.2	—	4.5	—
Silicocarnotite...........	11.5	11.8	29.1	27.5	—	25.8	—
Wheat on Sassafras Silt Loam (Beltsville, Md.)—C‡ (All nutrients in the placements)							
Monocalcium phosphate....	28.2	—	34.4	29.9	—	29.3	—
Dicalcium phosphate.......	12.7	—	25.5	31.8	—	25.4	—
Tricalcium phosphate......	16.1	—	23.2	16.3	—	10.5	—
Hydroxylapatite...........	5.6	—	6.7	5.8	—	4.2	—
Fluorapatite*.............	4.7	—	4.8	4.2	—	4.0	—
Silicocarnotite...........	12.6	—	29.8	30.3	—	29.2	—

*Tennessee brown-rock phosphate.

†"A" and "B" were run at different times on the same plan, except the band below was added in B and the 60% mixing substituted for the 40 and 100% mixings.

‡Run simultaneously with "B" but differs from B and the others in that all nutrients were put in the placements and the contact band omitted.

TABLE 4.—*Analyses of variance of yields produced by various phosphates in several placements (mean squares).*

Source of variation	D.F.	Sudan grass on Newtonia	Wheat on Sassafras (A)
Part I			
Treatments	29	103.90***	322.88***
Phosphates	(5)	245.50***	1539.42***
Placements	(4)	350.97***	103.61***
Ph×Pl	(20)	19.09***	62.59***
Error	60	3.15	4.41

Part II

Source of variation	Sudan on Sassafras		Wheat on Sassafras (B)		Wheat on Sassafras (C)	
	D.F.	m.s.	D.F.	m.s	D.F.	m.s.
Treatments	23	485.45***	29	260.52***	23	373.24***
Phosphates	(5)	1735.15***	(5)	1112.55***	(5)	1402.87***
Placements	(3)	341.59***	(4)	66.27***	(3)	197.45***
Ph×Pl	(15)	96.12***	(20)	37.81***	(15)	65.18***
Error	48	13.72	58†	4.84	47†	8.15

***Significant, odds 999:1.
†Two degrees of freedom used in blocks, variance not shown.

superphosphate ammoniated to 2%, and superphosphate ammoniated to 3% were applied in the two band placements always at the same P_2O_5 rate. The nitrogen and potash carriers, except for the small amount of nitrogen in the ammoniated superphosphates, were mixed with all the soil. The average yields are shown in Table 6.

Relative to superphosphate both dicalcium phosphate and silicocarnotite gave low yields in both placements with both crops. This indicates that lowered yields in band placements with these phosphates are due to localization in the band rather than to contact between the seed and the phosphate. Actually, on the sudan grass, the contact band was significantly better than the band below for dicalcium phosphate. All the other phosphates showed the same trend,

TABLE 5.—*Average relative efficiencies of various phosphates in several placements (monocalcium phosphate equals 100).*

Phosphates	Placements				
	Contact abnd	2½% mixing	10% mixing	40% mixing	100% mixing
Monocalcium phosphate	100	100	100	100	100
Dicalcium phosphate	35	110	123	121	110
Tricalcium phosphate	58	73	80	75	61
Hydroxylapatite	38	40	40	55	44
Fluorapatite	31	30	33	49	37
Silicocarnotite	55	128	157	112	109

but differences were not significant. This trend was possibly due to there being, on this low-phosphate soil, inadequate available phosphorus within reach of the early root hairs of the seedlings when the band was removed a little from the seed. The superphosphates tended to produce lower yields as the degree of ammoniation increased, although the differences did not quite reach significance at the conventional odds due, probably, to the fact that only two replicates were used in this experiment.

TABLE 6.—*Effect of band location on response of Sudan grass and wheat to phosphates, average grams per pot dry-weight.*

Phosphate	Sudan grass*		Wheat†	
	Contact band	Band below	Contact band	Band below
Dicalcium phosphate	14.9	7.9	5.1	5.2
Silicocarnotite	11.4	8.0	4.4	5.3
Superphosphate	28.9	22.9	8.1	11.1
Ammoniated superphosphate (2%)	26.6	20.6	8.1	8.3
Ammoniated superphosphate (4%)	25.5	19.1	7.5	9.0

*First cutting only; second cutting showed no significant differences.
†Wheat plants were small due to high greenhouse temperatures but were otherwise normal.

EFFECT OF HAVING ONLY PHOSPHATE IN THE PLACEMENTS

In practice all nutrients are commonly applied in the same mixed fertilizer which is placed in a band or other special placement or broadcast. The question therefore arose as to whether different results might have been obtained in the experiments described in this paper had all the nutrients been applied in the same placements. The last two sets of wheat data in Table 3 were obtained simultaneously on the Sassafras soil. In B the phosphates only were applied in the placements, while in C the nitrogen and potash carriers were also applied in the placements. Germination injury was expected when the potash and nitrogen carriers were in contact with the seed and it was accordingly necessary to use the band below in order to compare the effects of band placements in the two cases.

Crop response to the various phosphates was affected in the same general manner by placement regardless of the location of the other nutrients. Dicalcium phosphate and silicocarnotite still gave relatively poor response in the band placement with the other phosphates also showing the same general relationships as before.

HYDROXYLAPATITE VERSUS FLUORAPATITE (PHOSPHATE ROCK)

The hydroxyl- and fluorapatites were used in all the placements, both at the standard rate and at three times that rate in two of the experiments, the one with Sudan grass on the Newtonia soil and the first wheat experiment (A) on the Sassafras soil. The resulting data (Table 7) afford an opportunity for more detailed comparison of these two phosphates than was possible with some of the others. With the Sudan grass both phosphates gave higher yields in the 2.5, 10, and

40% mixings than in the contact band or 100% mixing. The relation of placement to yield on the wheat crop was not clear, but it is evident that placement may affect returns from these phosphates under some conditions. Generally speaking, crop response to hydroxylapatite was better than to fluorapatite, but the relative standing of the two phosphates was affected by the rate of application and by crop and soil factors.

TABLE 7.—*Comparison of fluorapatite (phosphate rock) and hydroxylapatite at two rates and five different placements, yields in grams per pot dry-weight.*

Placements	Hydroxylapatite		Fluorapatite	
	Single rate	Triple rate	Single rate	Triple rate
Sudan Grass on Newtonia Silt Loam				
Contact band	13.0	17.5	9.3	10.3
2½% mixing	17.0	23.3	12.2	23.4
10% mixing	17.3	24.6	15.6	21.9
40% mixing	15.3	24.4	16.1	21.2
100% mixing	10.4	17.7	8.3	17.1
Wheat on Sassafras Silt Loam				
Contact band	13.7	18.2	14.2	14.5
2½% mixing	14.2	16.5	13.0	11.5
10% mixing	13.8	18.2	13.0	13.3
40% mixing	15.2	19.3	11.7	13.0
100% mixing	14.3	20.2	12.3	14.7

DIFFERENCES AT VARIOUS STAGES OF GROWTH

Data on the dry weight of a crop give the final result but tell nothing about the stage of development at which the differences appeared. In the Sudan grass experiment on the Newtonia soil the height of the plants was measured at frequent intervals, beginning 19 days after planting when the plants were 4 to 5 inches high. These data, which will not be presented in detail, indicate in general that differences due to placements and nature of the phosphate were apparent in the very early stages of growth and tended to become greater as growth proceeded. Qualitative observations on the experiements conducted at Beltsville led to the same conclusion. A portion of the Sudan grass data, plotted in Fig. 1, shows the trend for four of the placements with all six phosphates.

DISCUSSION

The results obtained in this investigation offer an explanation of the observation of Ross, *et al.* (7), that the response of crops to ammoniated superphosphates is differently affected by placement than is the response to plain superphosphate. As the proportion of di- and tricalcium phosphates in the material are increased through increasing degrees of ammoniation, localized placements should be relatively unfavorable to best crop response. Nonammoniated superphosphate, on the other hand, would not be expected to behave in that manner because response to its principal phosphatic component, monocalcium phosphate, is not unfavorably affected in a localized placement. Indications are thus strong that best results with heavily ammoniated

superphosphates will not be achieved by applying such phosphates in a band or other localized placement. Highest yields with these materials would be expected when they are mixed with the soil to some extent. Similarly, the results with silicocarnotite suggest that mixing with the soil will give the best results with basic slag.

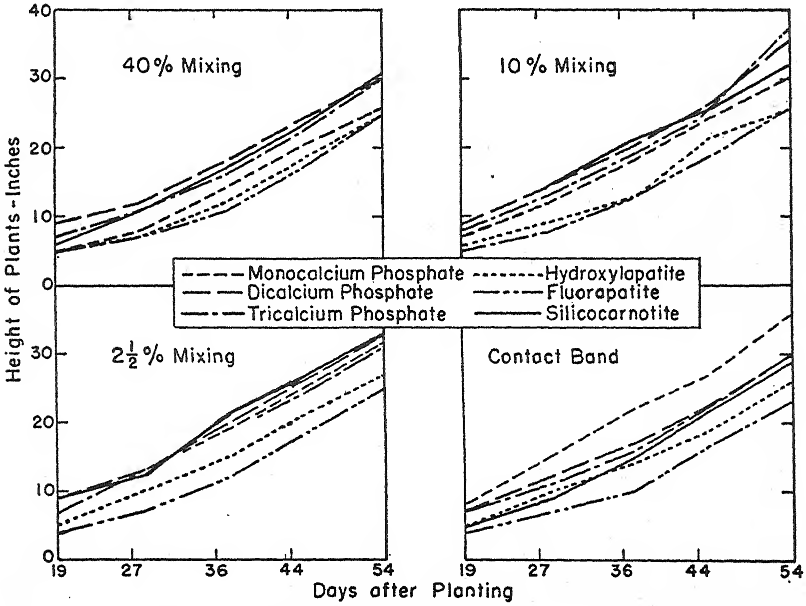

FIG. 1.—Growth rates of Sudan grass fertilized with mono, di-, or tri-calcium phosphate, hydroxylapatite, fluorapatite (phosphate rock), or silicocarnotite in four placements.

The relatively low response to the apatites was in line with expectations as was also the observation that fluorapatite, as phosphate rock, tended to give the lowest crop response of the two apatites under the conditions of these experiments. Ammoniation to such degree that large proportions of either of these compounds is formed would appear to be undesirable.

Where the seedling is able to reach supplies of readily available phosphorus adequate to meet its needs during early growth, one would expect the placement and nature of added phosphate fertilizer to be of less importance. As growth proceeds, phosphates initially relatively unavailable, whether due to their nature or placement, are reached by more root hairs and have time to react with the soil. Better utilization by the plant may then result. Levels of soil phosphorus are thus probably important to present considerations, placement and nature of phosphate being most important at low fertility levels.

In addition to the calcium phosphates mentioned, ammoniated superphosphate also contains ammonium phosphates but these were not included in the present study. From present considerations it does not seem possible to predict how these phosphates will behave in the various placements. It might be expected, however, that they would

behave similarly to monocalcium phosphate, or at least that monoammonium phosphate would thus behave. If such is the case the adverse effect of localized placement on some of the other phosphates in the ammoniated material may be somewhat neutralized by the ammonium phosphates.

SUMMARY

Greenhouse experiments were conducted to study the effect of varying placement on the response of crops to the calcium phosphates that occur in superphosphate, ammoniated superphosphate, and basic slag. Localization of the phosphate in a band placement or mixing with a limited proportion of the soil in the pot were optimum placements for monocalcium phosphate, the principal phosphatic component of superphosphate. Dicalcium phosphate and tricalcium phosphate, both found in ammoniated superphosphate, gave greatly reduced yields in the localized placement. This was especially true of dicalcium phosphate. Silicocarnotite, the principal phosphatic component of basic slag, was also adversely affected by a localized placement. Mixing with as little as 2½% of the soil greatly improved crop response to dicalcium phosphate and silicocarnotite and effected some improvement with tricalcium phosphate. Hydroxylapatite and fluorapatite (as phosphate rock) in general gave much lower crop response than the other phosphates and that response was less affected by varying placement. The results strongly suggest that best response to heavily ammoniated superphosphate or basic slag will be obtained when such materials are mixed with the soil to some extent. Bands or other localized placements should be relatively unfavorable.

LITERATURE CITED

1. ANDREWS, W. B. Discrepancies between the response of cotton to phosphatic materials and their availability as determined by the official method. Jour. Assoc. Off. Agr. Chem., 25:498–509. 1942.
2. BARRETT, R. L., and MCCAUGHEY, W. J. The system CaO-SiO_2-P_2O_5. American Mineralogist, 27:68–694. 1942.
3. COE, D. G., BARTHOLOMEW, R. P., VOLK, G. W., and WHITTAKER, C. W. The influence of placement on the efficiency of different calcium phosphates in greenhouse tests. (Preliminary report.) Proc. 19th Ann. Mtg. Natl. Joint Comm. on Fertilizer Application, Cincinnati, Ohio, Nov. 9, 1943, 12–17.
4. ENSMINGER, L. E., and COPE, JR., J. T. Effect of soil reaction on the efficiency of various phosphates for cotton and on loss of phosphorus by erosion. Jour. Amer. Soc. Agron., 39:1–11. 1947.
5. KEENAN, F. G. Reactions occurring during the ammoniation of superphosphates. Jour. Ind. & Eng. Chem., 22:1378. 1930.
6. MACINTIRE, W. H., HARDIN, L. J., OLDHAM, F. D., and HAMMOND, J. W. Development of P_2O_5 insolubility in phosphatic mixtures. The formation of fluorapatite as its cause. Ind. & Eng. Chem. 29:758–766. 1937.
7. ROSS, W. H., WHITTAKER, C. W., ADAMS, J. R., and RADER, L. F., JR. Effects of placement on response of crops to ammoniated and nonammoniated superphosphates on several soils. In press in this JOURNAL.
8. ———, JACOB, K. D., and BEESON, K. C. Composition and fertilizer efficiency of the insoluble phosphates in ammoniated superphosphates. Jour. Assoc. Off. Agr. Chem., 15:227–266. 1932.
9. RUBINS, E. J., and DEAN, L. A. Anion exchange in soils. II. Methods of study. Soil Sci., 63:389–397. 1947.
10. SALTER, R. M., and BARNES, E. E. The efficiency of soil and fertilizer phosphorus as affected by soil reaction. Ohio Agr. Exp. Sta. Bul. 553. 1935.
11. WILLIAMSON, J. T. Efficiency of ammoniated superphosphates for cotton. Jour. Amer. Soc. Agron., 27:724–728. 1935.

Carbohydrate Metabolism of Johnson Grass[1]

Karl E. Rapp[2]

JOHNSON grass, *Sorghum halepense*, is considered by many in the South to be a serious noxious weed very difficult to control or exterminate because of its extensive system of underground stems or rhizomes. A number of publications have appeared throughout temperate and tropical regions on methods for its control or eradication (2, 3, 6, 7, 10, 11, 12, 14, 19).[3] However, by means of its network of rhizomes and roots, the plant is ideal for retarding soil erosion and has been used successfully for this purpose in Texas (1). In addition to rendering this valuable service the grass has been grown and utilized for hay and pasture in many of the southern states (1, 4, 5, 9, 16, 20), Cuba (13), and the Mediterranean countries (15). The scope of its usefulness as a source of feed and industrial raw material could probably be broadened to such an extent that its agronomic advantages would overshadow its disadvantages. Considered in this light, the plant would rank high in stamina and productivity. In a fertile soil, it makes rapid growth, attains a height of over 6 feet, and produces seed in less than two months after sprouting.

The purpose of this investigation was to correlate with various stages of growth those substances in the plant included in the fraction called "plastic carbohydrate" by Pantanelli (15)—sucrose, reducing sugars, and starch and dextrins.

EXPERIMENTAL PROCEDURE

In the early spring of 1946 a sample of Johnson grass rhizomes was taken from a fence row for analysis and pot planting. This was about 3 weeks before sprouts began to appear in the parent stand. The rhizomes were cut into sections of 5 to 5.5 inches, each section having three nodes and a dry weight of 2 to 2.5 grams. Two of these sections were planted about 2 inches deep in each of 20 2-gallon pots of soil. A balance was attempted so that all pots initially contained an equal quantity of rootstock in 5 kilograms of virgin Maury silt loam from the Experiment Station farm.

After planting, the pots were numbered at random, placed in the greenhouse, and watered often enough to keep the soil moist. Sprouts had appeared in all the pots in 8 days. One month later, after the weather had moderated so that late frosts were improbable, the pots were moved out into the open.

Approximately 1 kilogram of the sections of rhizomes cut for planting was heated in an air oven at 80° C until fairly brittle. Drying to constant weight was completed in a vacuum oven at 60° C and 50 mm Hg. The sample was then ground to pass a 20-mesh screen, thoroughly mixed, and duplicate 5-gram samples were weighed for analysis. Using the semimicro method of Shaffer and Somogyi (17) as modified by Heinze and Murneek (8), the content of reducing sugar, total sugar, and starch and dextrins were determined on the oven-dry basis.

As the plants reached progressive stages of development the pots were emptied two at each stage in numerical order. Whole plants were harvested intact by re-

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[3]Figures in parenthesis refer to "Literature Cited", p. 873.

TABLE 1.—*Carbohydrate content of pot-grown Johnson grass at various stages of growth.*

Pot No.	Time after planting, days*	Part of plant	Weight per pot, grams	Reducing sugars as glucose, mgs per gram	Sucrose as glucose, mgs per gram	Starch and dextrins as glucose, mgs per gram	Total plastic carbohydrate as glucose, mgs per gram
0	0	Rhizome	4.5	117.5	184.5	30.7	332.7
1	30	Top	4.2	70.8	24.2	7.5	102.5
		Rhizome	4.0	125.9	123.1	12.9	261.9
		Fine root	7.1	10.1	10.4	0.9	21.4
2	30	Top	3.4	66.1	30.2	5.5	101.8
		Rhizome	3.8	172.0	52.7	8.3	233.1
		Fine root	3.4	7.8	19.1	1.2	28.1
3	51	Top	6.1	48.9	2.0	6.8	57.7
		Rhizome	7.6	192.5	45.3	19.1	256.9
		Fine root	3.6	19.6	5.0	4.6	29.2
4	51	Top	4.3	49.7	0.9	13.7	64.4
		Rhizome	7.7	180.0	14.8	16.0	210.8
		Fine root	3.2	15.1	3.3	3.9	22.3
5	78	Top	10.2	11.5	28.4	6.7	46.5
		Rhizome	10.4	63.3	116.7	14.9	194.9
		Fine root	4.2	9.0	34.3	4.3	47.5
6	78	Top	12.8	14.7	29.9	5.1	49.7
		Rhizome	9.8	87.7	121.4	20.2	229.3
		Fine root	4.8	8.7	26.1	2.8	37.6
7	119	Top	16.5	18.0	36.1	10.3	64.4
		Rhizome	8.3	35.4	106.1	15.0	156.5
		Fine root	5.7	11.5	17.2	4.2	32.8
8	119	Top	20.1	15.1	44.0	10.2	69.3
		Rhizome	8.8	46.4	123.2	7.9	177.5
		Fine root	8.2	7.1	11.0	0.7	18.9
9	144	Top	21.7	10.4	26.1	20.1	56.7
		Rhizome	10.2	45.1	96.2	33.3	174.6
		Fine root	5.6	8.5	13.8	5.0	27.3
10	144	Top	25.9	11.7	28.9	9.5	50.1
		Rhizome	9.7	44.4	97.7	16.8	158.8
		Fine root	6.4	7.2	8.3	1.4	16.9
11	181	Top	27.0	8.2	10.8	4.5	23.5
		Rhizome	13.9	48.1	97.3	30.2	175.6
		Fine root	11.8	3.5	5.1	2.8	11.4
12	181	Top	31.9	10.3	17.5	5.2	33.0
		Rhizome	18.0	36.8	76.9	24.4	138.1
		Fine root	11.8	6.1	8.2	0.5	14.7
13	332	Rhizome	18.1	85.3	185.1	13.0	283.4
		Fine root	7.0	2.9	5.3	1.3	9.4

TABLE 1.—*Concluded.*

Pot No.	Time after planting, days*	Part of plant	Weight per pot, grams	Reducing sugars as glucose, mgs per gram	Sucrose as glucose, mgs per gram	Starch and dextrins as glucose, mgs per gram	Total plastic carbohydrate as glucose, mgs per gram
14	332	Rhizome	18.9	53.2	154.7	19.1	227.0
		Fine root	8.4	4.1	6.8	2.7	13.6
15	365	Rhizome	15.8	81.9	181.0	25.7	288.6
		Fine root	7.1	4.1	5.9	1.7	11.7
16	365	Rhizome	14.7	119.7	191.6	19.9	331.1
		Fine root	8.1	3.8	6.7	3.0	13.4

*Shooting took place in 32 to 38 days, heading in 41 to 50 days, and seed formation in 48 to 50 days after planting.

moving the contents of each pot and washing the roots free of adhering soil. The plants from each pot were divided into tops, rhizomes, and fine roots, and the three pairs of samples so obtained at each harvesting were dried, ground, and analyzed in the same manner as the original rhizomes.

RESULTS AND DISCUSSION

Data and results on growth and carbohydrate content of the various samples are given in Table 1. Attention is called to the first 30 days in which the rhizomes lost weight in supplying food for the rapidly growing sprouts before the root system was developed. Likewise during the 51 days prior to formation of the seed, the sucrose was converted to the more mobile reducing sugars. After the seeds were formed, the process was reversed for carbohydrate storage in the rhizomes.

Rainfall was excessive during the period from the 96th to the 115th day, and the pots were soaked much of this time. In view of the values obtained immediately following this period the rapid top growth apparently was made at the expense of the carbohydrate stored in the rhizomes. A late second growth was responsible for the less pronounced irregularities around 150 days after planting.

Carbohydrate production and storage in each part of the plant may be followed by the curves in Fig. 1. In plotting these composite curves, the values from Table 1 were first converted to a grams-per-pot basis and the pair-harvested pots were averaged to obtain the respective points. In all probability the carbohydrate production values shown here are somewhat lower than those attained by plants grown in the field under good conditions, for not only did the pot-grown plants undergo a 19-day soaking period, but near the end of the growing season they became somewhat pot bound. Nevertheless the results are probably more representative of actual carbohydrate production and storage than could have been obtained from sampling of field-grown plants. Some of the rhizomes produced were about 3 feet long, coiled inside the pot. This extensive rhizome growth on plants in an open field would prevent accurate sampling to ascertain actual carbohydrate

production. Rhizome growth under various field conditions has been studied (18). Relationships between top growth and rhizome production in that investigation are in agreement with those in this study of pot-grown plants.

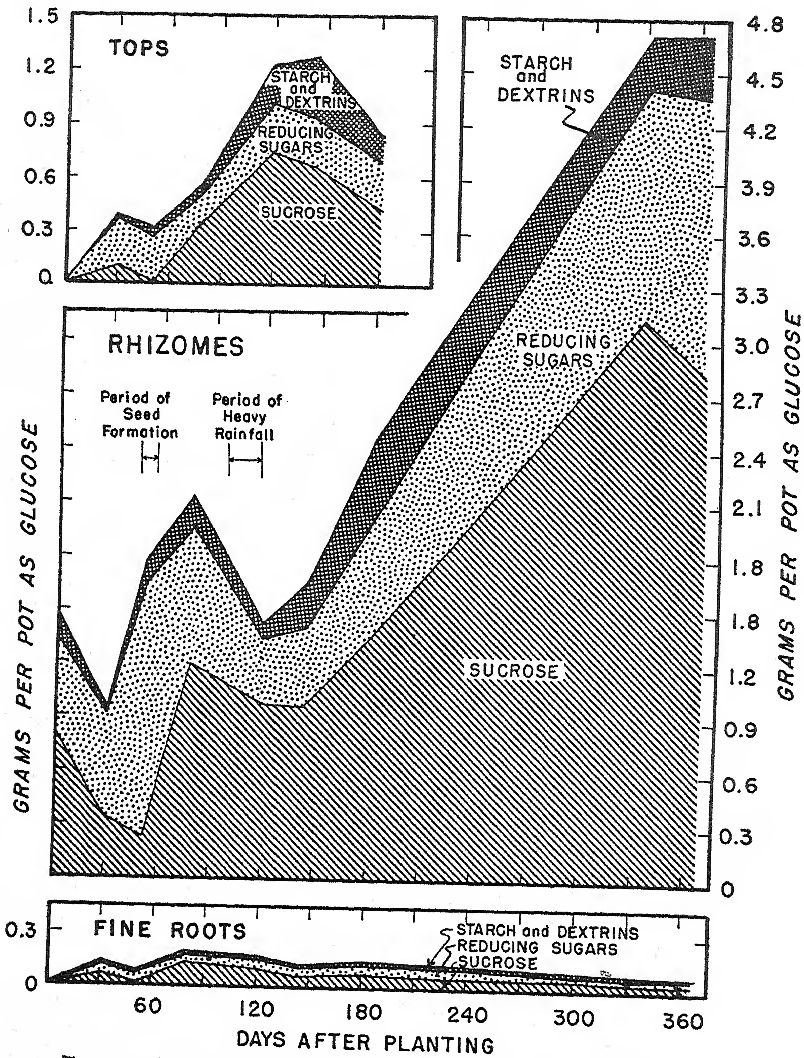

FIG. 1.—Carbohydrate production in tops, rhizomes, and fine roots.

SUMMARY AND CONCLUSIONS

The growth and carbohydrate content of Johnson grass grown in pots were observed over the period of a year. During the early stages of growth, metabolic reactions favored the formation of glucose to

support the young sprouts, and carbohydrate reserves in the rhizome were actually depleted before the occurrence of shooting. As the plant developed, sucrose became the predominant carbohydrate and remained so in all parts of the plant well into the growing season. After maturity was reached, the carbohydrate in the top was transported as glucose to the rhizome where it was reconverted to sucrose for winter storage.

Considered as a cultivated crop on soils subject to excessive erosion, Johnson grass could easily become an important factor in our soil economy. With this grass, a forage crop is made available which may be pastured or cut for hay or an underground crop furnishing carbohydrates for livestock feeding, sugar and syrup manufacture, or industrial alcohol production. The plant's carbohydrate metabolism in producing seed is the key to the success of control or eradication measures based on prevention of seed formation by repeated early plowing or mowing.

LITERATURE CITED

1. Briggs, G. Cropping with Johnson grass. Country Gentleman, 114:18. Aug. 1944.
2. Brown, C. W. Johnson grass, troublesome on lucerne flats. Agr. Gaz. New South Wales, 50:595. 1939.
3. Cates, J. S., and Spillman, W. J. A method of eradicating Johnson grass. U. S. D. A. Farmers' Bul. 279. 1907.
4. Crosby, M. A. Preparing Johnson grass hay for market in the Black Prairie belt of Alabama and Mississippi. U.S.D.A. Farmers' Bul. 1574. 1928.
5. Grimes, J. C., and Taylor, W. C. Johnson grass hay versus timothy hay for horses and mules. Ala. Agr. Exp. Sta. Circ. 54. 1930.
6. Harper, H. J. The use of sodium chlorate in the control of Johnson grass. Jour. Amer. Soc. Agron., 22:417. 1930.
7. Heard, H. C. Johnson grass control. Ari. Agr. Exp. Sta. Bul. 82. 1917.
8. Heinze, P. H., and Murneek, A. E. Comparative accuracy and efficiency in determination of carbohydrates in plant material. Mo. Agr. Exp. Sta. Res. Bul. 314. 1940.
9. Howard, B. Putting a pest to work. Country Gentleman, 83:7. June, 1918.
10. Latshaw, W. L., Zahnley, J. W., and Pickett, W. F. Weed eradication with chemical sprays. Kan. Agr. Exp. Sta., 6th Bien. Rpt., 42. 1932.
11. Lee, O. C. Johnson grass control is a community job. Purdue Univ. Agr. Ext. Circ. 256. 1944.
12. Marchionatto, J. B. Argentine Republic: Eradication of Aleppo grass by sodium chlorate. Intr. R. Agr., 25:242M. 1934.
13. Mastio, F. Utilizacion agricola e industrial de la cañuela o yerba de don Carlos, segun el professor E. Pantanelli. R. de Ag. Cuba, 7: No. 8, 40. 1925.
14. Pammel, L. H., and King, C. M. Johnson grass as a weed in southwestern Iowa. Iowa Agr. Exp. Sta. Circ. 55. 1919.
15. Pantanelli, E. Utilization of "cannarecchia" or "sorgagna" (*Sorghum halepense*). Staz. Sper. Agron. Ital., 52:405. 1919.
16. Perkins, W. R. Johnson grass. La. Agr. Ext. Circ. 10. 1916.
17. Shaffer, P. A., and Somogyi, M. Copper-iodometric reagents for sugar determination. Jour. Biol. Chem., 100:695. 1933.
18. Sturkie, D. G. The influence of various top-cutting treatments on rootstocks of Johnson grass (*S. halepense*). Jour. Amer. Soc. Agron., 22:82. 1930.
19. White, C. T. Queensland weeds. Johnson grass and wild sorghum. Queensland Agr. Jour., 47:365. 1937.
20. Whittle, C. A. Johnson grass for hay. Hoard's Dairyman, 52:47. 1916.

Effect of Environment and Source of Seed on Yield and Other Characters in Rice[1]

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ONE of the basic requirements for successful rice production is the use of good seed, that is, relatively pure and viable seed of varieties adapted to the prevailing climatic and soil conditions. It is customary among some rice growers to purchase new seed every few years because of a belief that their seed has deteriorated or "run out". Often the new seed is purchased from other states. This is more expensive than home-grown seed because of transportation costs. The seed of rice, as that of other self-pollinated crops may deteriorate in quality as a result of mechanical mixture of varieties, natural crossing, disease infection, and contamination with weed seeds. The need for purchasing new seed can usually be eliminated, however, by more careful attention to maintaining the purity and quality of home-grown seed.

To determine the effect of source of seed on yield and other characters in rice, an experiment was conducted at four rice experiment stations from 1937 to 1941, and the results are reported here.

MATERIAL AND METHODS

The Caloro (short-grain), Early Prolific (medium-grain), and Fortuna (long-grain) varieties were used. Caloro is the principal variety grown in California, and Early Prolific and Fortuna are important commercial varieties grown in the southern states. Each year seed of Caloro and Early Prolific was exchanged between the four rice stations located at Stuttgart, Ark., Crowley, La., Beaumont, Tex., and Biggs, Calif., and seed of Fortuna was exchanged between the three southern stations.

In 1937, the seed of Fortuna from Arkansas was a slightly earlier strain than regular Fortuna, and in 1940 the seed of Early Prolific from Texas was not entirely typical of this rather non-uniform variety. It is not likely, however, that these minor differences had any marked effect on the average results obtained. The results for 1940 in Louisiana are omitted because the crop was badly damaged by floods.

The experiment was designed to give accurate yield comparisons of the crops grown from seed of the same variety but from different sources. Thus, all plots of the same variety were grown in a group. The lots were randomized within each group and the varieties were randomized within each of the four replications.

The analysis of variance method was used to analyze the yield data. The F test was employed to determine whether a variation was significant. The t test was used to compare the means when the variation in yield was shown to be significant by the F test. For the other characters studied, the t test for small numbers was used to determine whether a difference was significant.

After storage for several weeks under like conditions, composite grain samples of each variety for each source of seed and from each station were well mixed,

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aspirated twice, and the test weight determined. Samples of each seed lot were soaked for 30 minutes in a 0.2% Semesan solution and then placed between blotters in a germinator at a temperature of 30° C.

Portions of the aspirated samples were sent to W. D. Smith, Grain Branch, Production and Marketing Administration, U. S. Dept. of Agriculture, New Orleans, La., for shelling tests, which were made by Jules J. Deffers of that office. The remainder of each aspirated sample was reduced in size with a Boerner divider and the weight of duplicate lots of 100 seeds was determined. The hulls were then removed by hand from the two 100-seed lots, and the weight of the kernels recorded. The difference in seed and kernel weights gave the weight or percentage of hulls.

The varieties were grown at the different stations, and the yields were recorded by the same men each year. Likewise, the data reported for the other characters studied also were recorded by the same men each year. Thus, the results were not subject to variations due to changes in personnel.

In the text and tables, the stations and sources of seed are referred to as Arkansas, Louisiana, Texas, and California.

EXPERIMENTAL RESULTS

YIELDS

The average yields and the average data for the other characters studied were affected much more by location (station) and season than by the source of seed. Therefore, the source of seed is disregarded and data on the effect of location and season on annual and average yields, and on average data for the other characters studied, are presented in Table 1.

At each station, the annual yield of each variety reported in Table 1 is the average of 12 or 16 plots. The average annual yield of each variety for the three or four stations is based upon a total of 36 to 64 plots, and the 4- or 5-year average yields of each variety are based upon 64 or 80 plots. At each station, the average yields of each variety varied materially from year to year. For example, during the 4- or 5-year periods, the yield of Caloro in Arkansas ranged from 38.9 to 55.3 bushels, in Louisiana from 31.0 to 58.3 bushels, in Texas from 33.0 to 44.2 bushels, and in California from 70.0 to 94.2 bushels per acre. In the same periods, marked variations also occurred in the annual yields of Early Prolific and Fortuna at the respective stations. The environmental factors responsible for such wide annual variations in the yield of the same variety grown on the same soil type by essentially the same cultural and irrigation methods are not too well understood.

The average yields from seed of different sources for the 4- or 5-year period and average data for the other characters studied on the respective stations are shown in Table 2.

In a total of 57 yield comparisons or tests with seed of the three varieties from different sources only 10 showed significant differences. In Louisiana, the average yield of Caloro was significantly higher from California seed than from Arkansas, Louisiana, and Texas seed. The average yields of Early Prolific were significantly higher in Arkansas from the Louisiana and Texas seed than from Arkansas and California seed; in Louisiana, from California and Texas seed than from Louisiana and Arkansas seed, the average yields from the Louisiana seed being significantly higher than from the Arkansas seed; and in California, from California seed than from Arkansas and Louisiana seed.

TABLE 1.—*Annual and average yields and average data for other characters studied of three varieties of rice grown at different rice experiment stations in the United States from 1937 to 1941.*

Year	Variety													
	Caloro grown in					Early Prolific grown in					Fortuna grown in			
	Ark.	La.	Tex.	Calif.	Av.	Ark.	La.	Tex.	Calif.	Av.	Ark.	La.	Tex.	Av.
	Yield Per Acre, Bushels													
1937	55.3	58.3	44.2	70.0	56.9	49.1	54.1	39.3	52.7	48.8	43.2	63.0	45.3	50.5
1938	49.9	31.0	38.4	94.2	53.4	46.3	38.2	28.5	83.9	49.2	54.8	44.7	46.1	48.5
1939	49.8	49.0	38.0	91.1	57.0	31.0	38.6	27.6	75.0	43.1	49.9	49.0	37.2	45.4
1940	38.9	—	36.1	92.2	55.7	32.5	—	34.0	84.3	50.3	34.5	—	44.2	39.4
1941	47.6	29.5	33.0	72.4	45.6	50.9	26.9	29.0	57.0	41.0	52.5	40.5	38.0	43.7
Av.	48.3	42.0	37.9	84.0	—	42.0	39.5	31.7	70.6	—	46.9	49.3	42.2	—
	Test Weight, Pound													
1937	45.0	43.9	45.0	45.0	44.7	41.3	41.5	44.6	41.6	42.3	42.3	41.8	43.3	42.5
1938	43.3	45.5	47.0	44.0	45.0	40.3	41.6	44.8	43.4	42.5	43.0	43.0	45.0	43.7
1939	43.6	45.8	45.2	44.3	44.7	40.3	42.0	44.9	43.1	42.6	43.0	44.3	46.0	44.4
1940	43.0	—	45.0	46.1	44.7	42.0	—	43.0	44.9	43.3	42.0	—	44.0	43.0
1941	45.3	42.0	46.0	44.3	44.4	43.0	—	44.3	43.3	43.5	43.0	42.0	45.0	43.3
Av.	44.0	44.3	45.7	44.7	—	41.5	41.7	44.3	43.3	—	42.7	43.0	44.7	—
	Germination, %													
1937	99.5	88.5	89.5	99.8	94.3	98.0	93.8	95.5	98.5	96.5	97.7	97.7	97.0	97.5
1938	96.3	87.3	95.8	98.5	94.5	97.8	91.5	96.2	98.8	96.1	98.7	94.2	99.7	97.5
1939	99.0	96.0	96.5	97.5	97.3	97.8	93.0	97.8	99.2	97.0	99.7	98.0	98.7	98.8
1940	96.0	—	93.5	99.8	96.4	97.8	—	94.2	99.0	97.0	91.7	—	98.2	95.0
1941	96.0	79.0	94.0	98.0	91.8	98.2	88.0	95.5	98.2	95.0	97.0	93.7	99.7	96.8
Av.	97.1	87.7	93.9	98.7	—	97.9	91.8	95.9	98.8	—	97.0	96.0	98.8	—

						Grain Weight, mg								
1937	27.4	27.2	26.0	29.3	27.5	26.6	28.7	27.9	30.0	28.3	29.4	27.4	28.2	28.3
1938	25.2	27.0	25.9	29.5	26.9	24.7	28.0	26.3	29.5	27.1	28.9	29.0	29.1	29.0
1939	24.4	26.7	25.7	28.8	26.4	22.0	26.5	26.8	28.8	26.0	27.7	28.0	27.4	27.7
1940	26.0	—	25.4	29.8	27.1	25.6	—	26.3	30.3	27.4	29.0	—	28.9	29.0
1941	25.2	24.5	26.8	27.7	26.1	24.5	26.7	27.9	28.0	26.8	27.7	28.2	28.6	28.2
Av.	25.6	26.4	25.9	29.0	—	24.7	27.5	27.1	29.3	—	28.5	28.1	28.4	—
						Kernel Weight, mg								
1937	22.6	22.5	21.1	24.0	22.6	20.9	22.7	21.9	23.6	22.3	23.4	21.4	22.2	22.3
1938	20.4	22.1	21.2	24.5	22.1	19.0	21.8	20.5	23.5	21.2	22.6	22.8	23.1	22.8
1939	19.5	21.8	20.9	23.4	21.4	16.9	20.6	20.9	22.4	20.2	21.6	22.2	21.7	21.8
1940	21.4	—	20.5	24.4	22.1	20.1	—	20.4	23.8	21.4	23.1	—	22.8	23.0
1941	20.3	19.6	21.8	22.9	21.2	19.0	20.3	21.7	22.1	20.8	21.6	22.1	22.8	22.2
Av.	20.8	21.5	21.1	23.8	—	19.2	21.4	21.1	23.1	—	22.5	22.2	22.5	—
						Hulls, %								
1937	17.8	17.2	18.9	18.0	18.0	21.2	20.8	21.4	21.1	21.1	20.4	21.3	21.4	21.0
1938	19.3	18.2	18.2	17.0	18.2	23.3	22.2	22.0	20.4	22.0	21.7	21.3	20.5	21.2
1939	19.8	18.3	18.5	19.0	18.9	23.4	22.3	22.0	22.3	22.5	22.1	20.8	20.8	21.2
1940	18.4	—	19.4	18.0	18.6	21.4	—	22.4	21.4	21.7	20.2	—	21.1	20.7
1941	19.4	20.2	18.6	17.3	18.9	22.3	23.8	22.3	21.3	22.4	22.0	21.7	20.4	21.4
Av.	18.9	18.5	18.7	17.9	—	22.3	22.3	22.0	21.3	—	21.3	21.3	20.8	—
						Yield of Whole Kernels, %								
1937	79.3	68.6	73.4	76.1	74.4	75.6	74.6	73.2	69.6	73.3	66.7	48.7	65.8	60.4
1938	77.1	76.9	79.2	77.7	77.7	71.6	71.5	74.3	73.4	72.7	58.2	58.0	73.8	63.3
1939	69.1	72.2	76.1	69.2	71.7	70.4	69.9	73.1	63.6	69.3	62.2	56.3	56.6	58.4
1940	78.5	—	67.5	74.3	73.4	74.8	—	74.9	62.2	70.6	70.7	—	65.2	68.0
1941	75.5	74.6	78.6	80.5	77.3	75.0	63.9	74.2	76.7	72.5	68.1	65.2	73.0	68.8
Av.	75.9	73.1	74.9	75.5	—	73.5	70.6	73.9	69.1	—	65.2	56.5	66.9	—

TABLE 1.—*Concluded.*

Year	Caloro grown in Ark.	Caloro grown in La.	Caloro grown in Tex.	Caloro grown in Calif.	Caloro grown in Av.	Early Prolific grown in Ark.	Early Prolific grown in La.	Early Prolific grown in Tex.	Early Prolific grown in Calif.	Early Prolific grown in Av.	Fortuna grown in Ark.	Fortuna grown in La.	Fortuna grown in Tex.	Fortuna grown in Av.
Yield of Broken Rice, %														
1937	1.6	12.1	5.3	3.8	5.7	1.6	3.4	3.2	7.5	3.9	10.0	27.5	9.8	15.8
1938	2.9	5.4	1.1	3.8	3.3	3.4	6.4	2.1	5.3	4.3	18.0	19.1	3.6	13.6
1939	9.1	6.8	3.0	10.0	7.2	4.3	6.5	3.2	12.5	6.6	13.7	20.8	19.0	17.8
1940	2.3	—	11.4	6.3	6.7	3.0	—	2.1	14.7	6.6	8.0	—	12.8	10.4
1941	4.9	3.5	1.5	1.4	2.8	2.2	11.0	3.2	2.1	4.6	9.1	11.7	5.4	8.7
Av.	4.1	6.9	4.5	5.1	—	2.9	6.8	2.8	8.4	—	11.8	19.8	10.1	—
Yield of Total Rice, %														
1937	80.8	80.6	78.7	80.4	80.1	77.2	78.0	76.4	77.1	77.2	76.7	76.1	75.6	76.1
1938	80.0	82.2	80.3	81.5	81.0	75.0	77.9	76.4	78.7	77.0	76.2	77.1	77.4	76.9
1939	78.1	78.9	79.1	79.1	78.8	74.7	76.4	76.3	76.1	75.9	75.9	77.0	75.6	76.2
1940	80.8	—	78.9	80.6	80.1	77.8	—	77.0	77.1	77.3	78.7	—	77.9	78.3
1941	80.4	78.1	80.1	81.9	80.1	77.2	77.4	77.3	78.8	77.7	77.2	76.9	78.3	77.5
Av.	80.0	80.0	79.4	80.7	—	76.4	77.4	76.7	77.6	—	76.9	76.8	77.0	—

None of the differences in average yields of Fortuna from different sources of seed was significant.

The average yields of Caloro and Early Prolific for the four stations ranged from 47.8 bushels from Arkansas seed to 51.4 bushels per acre from California seed (Table 2). The average yields of the three varieties for the three southern stations varied from 47.5 bushels from Arkansas seed to 48.6 bushels per acre from Texas seed. These relatively small differences in the average yields of the three varieties from seed of different sources apparently are not significant. The results indicate, therefore, that local seed of good germination, free of mixtures, and free of weed seeds is usually as productive as that obtained from other rice-producing states.

A comparison of the 4- or 5- year average yields of the three varieties at each station shows (1) that in Arkansas, the average yields of the Caloro and Fortuna varieties were significantly higher than those of Early Prolific; (2) that in Louisiana and Texas, the yields of Fortuna were significantly higher then those of Caloro and Early Prolific; and (3) that in California and Texas, the yields of Caloro were significantly higher than those of Early Prolific.

TEST WEIGHT

The average annual test weight of the grain of each variety varied consistently at each station (Table 1). The average test weight of each variety from all stations was essentially the same each year. However, the average test weight of Early Prolific from California and Texas was significantly higher than that of the same variety from Arkansas and Louisiana. The source of seed had no appreciable effect on the average test weight of any of the varieties at the respective stations, as shown in Table 2.

Test weight in rice is affected mainly by (1) the thickness and pubescence of the hulls, (2) stage of maturity when harvested, (3) injury to the developing or mature grain by insects and diseases, (4) the extent of dehulling in threshing, and (5) the amount of trash present, including stems, chaff, mud lumps, and other foreign material. The deleterious effect of certain of these factors on the test weight of the grain can be reduced to some extent by exercising good judgment in determining the proper time to harvest the crop and by careful threshing, cleaning, and storage operations.

GERMINATION

The germination of each variety from the respective stations varied somewhat from year to year (Table 1). The average germination of Caloro and Early Prolific was significantly higher from California and Arkansas seed than from Louisiana and Texas seed, and also from Texas seed than from Louisiana seed. The average germination of Fortuna was essentially the same from the Arkansas, Louisiana, and Texas seed. The average germination of each variety for all stations was, however, relatively high each year, ranging from 87.7% for Caloro from Louisiana to 98.8% for Early Prolific from California and for Fortuna from Texas.

TABLE 2.—*Average yields and average data for other characters studied of three varieties of rice grown from seed of different sources at three or more rice experiment stations in the United States in the period 1937–1941.*

Source of seed	Variety														Average for	
	Caloro grown in					Early Prolific grown in					Fortuna grown in				Caloro and Early Prolific	Caloro, Early Prolific, and Fortuna
	Ark.	La.	Tex.	Calif.	Av.	Ark.	La.	Tex.	Calif.	Av.	Ark.	La.	Tex.	Av.		
	Yield Per Acre, Bushels															
Arkansas	46.9	39.5	39.8	84.3	52.6	40.7	34.4	29.6	66.8	42.9	47.1	50.3	43.5	47.0	47.8	47.5
Louisiana	46.8	41.7	37.3	85.7	52.9	43.8	38.6	32.3	68.3	45.8	46.2	48.6	41.1	45.3	49.3	48.2
Texas	47.8	38.5	36.9	81.7	51.2	44.5	42.0	32.9	71.5	47.7	47.5	49.0	41.9	46.1	49.5	48.6
California	51.6	48.2	37.8	84.2	55.4	38.8	42.9	31.9	75.6	47.3	—	—	—	—	51.4	—
Average	48.3	42.0	37.9	84.0	—	42.0	39.5	31.7	70.6	—	46.9	49.3	42.2	—	—	—
	Test Weight, Pounds															
Arkansas	44.2	44.0	45.6	45.0	44.7	41.6	42.0	44.3	43.2	42.8	42.9	42.8	44.8	43.5	43.7	43.7
Louisiana	44.0	44.4	45.6	44.6	44.7	41.3	42.0	44.2	43.1	42.2	42.6	43.4	44.6	43.5	43.4	43.4
Texas	44.1	44.4	45.6	44.6	44.7	41.3	41.3	44.6	43.4	42.7	42.5	43.0	44.6	43.4	43.7	43.6
California	43.8	44.5	45.8	44.7	44.7	41.2	41.5	44.1	43.3	42.6	—	—	—	—	43.6	—
Average	44.0	44.3	45.7	44.7	—	41.5	41.7	44.3	43.3	—	42.7	43.0	44.7	—	—	—
	Germination, %															
Arkansas	98.4	88.0	93.0	99.0	94.6	98.2	93.0	95.4	98.8	96.4	98.8	95.2	98.8	97.6	95.5	96.1
Louisiana	96.4	87.0	93.6	98.0	93.8	97.6	92.0	96.0	99.0	96.2	95.2	97.2	98.4	76.9	95.0	95.5
Texas	96.8	89.5	94.4	99.0	94.9	97.6	90.8	95.8	98.8	95.8	97.0	95.2	98.4	96.9	95.3	95.8
California	96.6	86.3	94.4	98.8	94.0	98.2	90.5	96.2	98.8	95.9	—	—	—	—	95.0	—
Average	97.1	87.7	93.9	98.7	—	97.9	91.6	95.9	98.8	—	97.0	95.7	98.5	—	—	—

Grain Weight, mg																
Arkansas	25.5	26.0	25.5	29.0	26.5	24.5	27.3	26.6	28.9	26.8	28.3	28.2	28.6	28.4	26.7	27.1
Louisiana	25.4	26.4	26.1	29.0	26.7	25.0	27.3	27.3	29.5	27.3	28.7	28.3	28.4	28.5	27.0	27.4
Texas	25.7	26.1	26.1	28.9	26.7	24.3	27.0	26.6	28.8	26.7	28.5	27.9	28.3	28.2	26.7	27.1
California	26.0	26.8	26.1	29.1	27.0	25.1	28.3	27.7	30.2	27.9	—	—	—	—	27.5	—
Average	25.6	26.4	25.9	29.0	—	24.7	27.5	27.1	29.3	—	28.5	28.1	28.4	—	—	—
Kernel Weight, mg																
Arkansas	20.8	21.2	20.7	23.9	21.7	19.0	21.2	20.8	22.6	20.9	22.4	22.2	22.7	22.4	21.5	21.8
Louisiana	20.5	21.6	21.3	23.9	21.8	19.3	21.3	21.3	23.1	21.3	22.6	22.4	22.5	22.5	21.5	21.8
Texas	20.9	21.3	21.2	23.8	21.8	18.9	21.0	20.8	22.7	20.9	22.4	22.0	22.3	22.2	21.3	21.6
California	21.2	22.0	21.3	23.8	22.1	19.5	21.9	21.6	23.8	21.7	—	—	—	—	21.9	—
Average	20.8	21.5	21.1	23.8	—	19.2	21.4	21.1	23.1	—	22.5	22.2	22.5	—	—	—
Hulls, %																
Arkansas	18.8	18.5	18.9	17.8	18.5	22.4	22.3	22.1	21.7	22.1	20.9	21.3	20.7	21.0	20.3	20.5
Louisiana	19.5	18.4	18.7	17.7	18.6	22.3	22.0	21.9	21.4	21.9	21.5	20.9	20.8	21.1	20.2	20.5
Texas	18.9	18.8	18.8	17.8	18.6	22.3	22.3	21.8	20.9	21.8	21.4	21.6	21.0	21.2	20.2	20.5
California	18.5	18.2	18.5	18.1	18.3	22.3	22.5	22.3	21.1	22.1	—	—	—	—	20.2	—
Average	18.9	18.5	18.7	17.9	—	22.3	22.3	22.0	21.3	—	21.3	21.3	20.8	—	—	—
Yield of Whole Kernels, %																
Arkansas	76.2	72.5	75.0	74.8	74.6	73.6	72.5	73.9	70.7	72.7	66.6	57.6	68.0	64.1	73.7	71.0
Louisiana	76.0	73.5	74.9	75.8	75.1	73.8	70.3	74.0	68.4	71.6	63.7	55.8	65.9	61.8	73.3	70.2
Texas	75.2	72.8	74.4	75.6	74.5	73.9	70.7	74.1	67.5	71.6	65.2	56.2	66.8	62.7	73.0	70.2
California	76.2	73.4	75.5	76.0	75.3	72.6	69.0	73.7	69.8	71.3	—	—	—	—	73.3	—
Average	75.9	73.1	74.9	75.5	—	73.5	70.6	73.9	69.1	—	65.2	56.5	66.9	—	—	—

TABLE 2.—*Concluded.*

Source of seed	Variety														Average for	
	Caloro grown in					Early Prolific grown in					Fortuna grown in				Caloro and Early Prolific	Caloro, Early Prolific, and Fortuna
	Ark.	La.	Tex.	Calif.	Av.	Ark.	La.	Tex.	Calif.	Av.	Ark.	La.	Tex.	Av.		
Yield of Broken Rice, %																
Arkansas	3.7	7.5	4.3	5.9	5.4	2.8	5.6	2.8	6.9	4.5	10.4	19.4	9.3	13.0	4.9	7.1
Louisiana	4.0	6.7	4.6	5.0	5.1	2.9	6.7	2.6	9.2	5.4	13.1	19.5	10.7	14.5	5.2	7.7
Texas	4.9	7.2	4.9	4.8	5.5	2.7	6.5	2.8	9.8	5.5	11.8	20.3	10.3	14.1	5.5	7.8
California	3.9	6.3	4.1	4.6	4.7	3.4	8.4	2.8	7.8	5.6	—	—	—	—	5.2	—
Average	4.1	6.9	4.5	5.1	—	2.9	6.8	2.8	8.4	—	11.8	19.8	10.1	—	—	—
Yield of Total Rice, %																
Arkansas	80.0	80.0	79.3	80.7	80.0	76.4	78.1	76.7	77.6	77.2	77.0	77.0	77.3	77.1	78.6	78.2
Louisiana	80.0	80.1	79.5	80.8	80.1	76.7	76.9	76.5	77.6	76.9	76.8	76.8	76.5	76.7	78.5	78.0
Texas	80.0	80.0	79.2	80.7	80.0	76.6	77.2	76.9	77.5	77.1	77.0	76.5	77.1	76.9	78.5	78.1
California	80.1	79.8	79.6	80.6	80.0	75.9	77.4	76.6	77.6	76.9	—	—	—	—	78.5	—
Average	80.0	80.0	79.4	80.7	—	76.4	77.4	76.7	77.6	—	76.9	76.8	77.0	—	—	—

The average germination of each variety for all stations was essentially the same for each source of seed (Table 2). The average germination of Caloro and Early Prolific for the 4- or 5-year period was significantly higher from Arkansas and California seed than from Louisiana and Texas seed; whereas, the average germination of Fortuna from each of the southern stations was essentially the same. The average germination of Caloro ranged from 87.7 from Louisiana seed to 98.8% from California seed and that of Early Prolific from 91.6% from Louisiana seed to 98.8% for California seed. The average for each variety, however, was above 90%, except for Caloro from Louisiana. Seed with a germination of 90% or above should give good stands of rice at the usual rate of seeding.

In Louisiana and Texas, Caloro and Early Prolific normally mature when temperatures and humidity are relatively high, hence, the grain may be more seriously injured by diseases and insects than that of late-maturing varieties. This may account in part for the lower average germination of Caloro and Early Prolific seed from Louisiana and Texas as compared with that from Arkansas and California.

GRAIN AND KERNEL WEIGHT

Grain (rough rice) weight is affected mainly by variety, location, soil fertility, stage of maturity when harvested, and injury by diseases and insects. The grain and kernel weights of each variety varied somewhat in different years at each station (Table 1), and in some years the differences were significant. For example, the differences for Caloro were significant in Arkansas between 1937 and 1939, in Louisiana between 1937 and 1941, in Texas between 1940 and 1941, and in California between 1937 and 1940; for Early Prolific, in Arkansas between 1938 and 1939, in Louisana between 1937 and 1939, in Texas, between 1937 and 1938, and in California between 1940 and 1941; and for Fortuna, in Arkansas between 1937 and 1941 and in Louisiana and Texas between 1937 and 1938.

The average annual grain and kernel weights of each variety for the three or four stations did not differ materially from year to year; however, both the average grain and kernel weights of Caloro and Early Prolific for the four stations were lower in 1939 and 1941 than in other years. The 5-year average grain and kernel weights of Caloro and Early Prolific from California were significantly higher than those of the same varieties from the other states. Likewise, the grain and kernel weights of Early Prolific from Louisiana and Texas were significantly higher than those from Arkansas. The sources of seed, however, had no appreciable effect on the average grain and kernel weights for the four stations (Table 2). Fortuna grain and kernels from each of the southern stations were of essentially the same weight.

The higher average grain and kernel weights of Caloro and Early Prolific from California as compared with those from the southern stations are probably due to a more fertile soil and freedom from disease and insect injury in California.

HULLS

Rice hulls are low in value, hence varieties having a low proportion of hulls in relation to grain weight are preferred by millers. In each of the varieties grown, the percentage of hulls varied to some extent from year to year at the respective stations, and the differences between certain years were significant, except for Fortuna in Louisiana (Table 1). For example, the differences in percentage of hulls were significant for Caloro in Arkansas between 1937 and 1939, in Louisiana between 1937 and 1941, in Texas between 1938 and 1940, and in California between 1938 and 1939; for Early Prolific, in Arkansas between 1938 and 1940, in Louisiana between 1937 and 1941, in Texas between 1937 and 1940, and in California between 1937 and 1939; and for Fortuna, in Arkansas between 1939 and 1940 and in Texas between 1937 and 1938.

Caloro and Early Prolific grain from California was significantly lower in percentage of hulls then that of the same varieties from the southern states. In each of the varieties grown, the 4- or 5-year average proportion of hulls was almost identical at each of the southern stations. The source of seed used had no appreciable effect on the average hull content of the grain produced at the four stations (Table 2). Hulls constitute a somewhat lower proportion of the grain weight of Caloro than of Fortuna and Fortuna a slightly lower proportion than that of Early Prolific. In the period grown, the average hull content for Caloro and Early Prolific was less variable than the grain and kernel weights. Of the characters studied, the percentage of hulls and the grain and kernel weights were less variable from year to year than the average yields per acre and the average milling quality.

MILLING QUALITY

Rice of good milling quality yields a high proportion of whole kernels (head rice), hence, a low proportion of broken rice in milling. These two products combined make up the total yield of milled rice. Head rice sells for a higher price than broken rice, so the price paid for a given lot of rough rice is based upon its apparent milling quality, that is, the relative proportions of head, broken, and total rice expected in milling.

In shelling tests, the annual yield of whole kernels and broken rice of each variety at each station varied materially from year to year (Table 1), and the differences between certain years and also between some stations were significant. For example, the differences in yield of whole kernels were significant for Caloro in Arkansas between 1937 and 1939, in Louisiana between 1937 and 1941, in Texas between 1937 and 1938, and in California betweeen 1939 and 1941; for Early Prolific in Arkansas between 1937 and 1938, in Louisiana between 1937 and 1941, in Texas between 1939 and 1940, and in California between 1937 and 1940; and for Fortuna in Arkansas between 1937 and 1938, in Louisiana between 1938 and 1941, and in Texas between 1938 and 1939.

In 1937, the yield of whole kernels for Caloro from Louisana was significantly less than that from Arkansas and California; for Early

Prolific in 1941 the yield of whole kernels was significantly lower than that from the other stations; and for Fortuna in 1937 the yield of whole kernels from Louisiana was significantly lower than that from Arkansas and Texas. Likewise, some of the average differences in the yield of whole kernels of each variety for the three or four stations were significant. For example, the average yield of whole kernels for Caloro was significantly higher in 1938 than in 1939, for Early Prolific in 1937 than in 1939, and for Fortuna in 1941 than in 1939.

At each station, the highest 4- or 5-year average yield of whole kernels was from Caloro, and Early Prolific ranked second. For Fortuna, the average yield of whole kernels was significantly higher from Arkansas and Texas grain than that from Louisiana but lower than that from Caloro and Early Prolific.

The 4- or 5-year average total milled rice yields of Caloro at each station were significantly higher than those of Early Prolific and Fortuna which were similar.

The average yields of whole kernels from Caloro and Early Prolific for the four stations were much the same from each source of seed (Table 2). Caloro from Louisiana gave a lower yield of whole kernels than Caloro from the other states. Early Prolific from California and Louisiana likewise gave lower average yields of whole kernels than the same variety from Arkansas and Texas. Fortuna from Louisana gave a much lower average yield of whole kernels than that from Arkansas and Texas. The average yields of whole kernels for Caloro and Early Prolific were essentially the same for all sources of seed. This also was true for the three varieties from the southern stations.

A high average yield of head rice is of course associated with a low average yield of broken rice. The location (station) and the variety had a marked effect upon the yield of broken rice; whereas, the source of seed had no appreciable effect on milling quality or total milled rice yield, nor were the differences for a given variety large at the respective stations (Table 2).

Milling quality is affected by the shape of the grain and, to a marked extent, by the nature of the weather just prior to maturity and during the harvest periods. Hence, wide variations in milling quality of a given variety occur at a given location from year to year, and also within the same area each year.

SUMMARY

An experiment was conducted at four rice experiment stations during the 5-year period of 1937–1941 to determine the effect of environment and source of seed on yields and other characters in three varieties of rice. Some of the differences in average yields and test weights were significant between years, stations, and varieties.

In 57 yield comparisons between seed of three varieties from different sources, only 10 differed significantly. The source of seed had no appreciable effect on the test weight of the grain produced at the different stations. This indicates that local seed of good quality, free of mixtures and weed seeds, is as productive as that obtained from other rice-producing states.

The germination of seed from the different stations was essentially the same for each source of seed, but the differences in germination of the varieties used were significant between some stations and between certain years.

The average grain and kernel weights within a variety were essentially the same for all sources of seed. However, both the grain and kernels of Caloro and Early Prolific from California were heavier than were those from the southern states. The grain and kernels of Caloro and Early Prolific from Arkansas were lighter than from Louisiana and Texas. However, the differences in average grain and kernel weights within each variety were comparatively small for all stations.

The source of seed had no appreciable effect on the proportion of hulls in relation to grain weight, but Caloro and Early Prolific grain from California had lower percentages of hulls than seed of these varieties from the southern states.

At each station, wide variations in milling quality occurred between varieties and years and also stations, but the source of seed had no effect upon the milling quality of the grain produced.

Potassium, Calcium, and Magnesium Balance and Recriprocal Relationship in Plants[1]

R. E. Lucas and G. D. Scarseth[2]

THE three basic cations, potassium, calcium, and magnesium, compose the largest portion of the essential nutrient elements found in plant ash. There exists an interrelationship between these three cations in plants (4,10),[3] and an understanding of this relationship is fundamental knowledge. Any practical or experimental design whose objective is to increase one of these cations in the plant must allow for the fact that the other cations will be decreased. The use of lime might increase the percentage content of calcium in the plant, but the content of magnesium and potassium may be lowered. The use of excessive amounts of potash will cause a very high content of potassium in the plant, but will lower the contents of calcium and magnesium. It is the purpose of this article to point out some of the factors which affect the cation content in plants.

Each of the basic cations perform certain well-known and specific physiological roles characteristic of the element. Any factor which interfers with these functions means a reduction in quality and quantity of plant growth. In spite of these specific essential functions attributed to only one element, there are many physiological functions performed in common by any of the three cations. Examples would include the buffering of cell sap, neutralization of organic acids, and regulation of salt concentration. The interchangeability of the basic cations in performing these chemical functions probably would have little or no effect on the yield and quality of the feed or food. In other words, there appears to exist in plants a fairly wide deviation from a theoretical balance for the performance of certain chemical functions. Any extreme deviation from a theoretical balance—a figure which only be roughly approximated—is not desirable, however, because many of the specific properties and functions of potassium, calcium, and magnesium are not interchangeable.

It is a well-known fact that there exists a mutual mechanical replacement of the basic elements in plants. This behavior is often referred to as "Ehrenberg's potash-lime law" (6) because he was one of the earliest men to report a reciprocal relationship between the contents of calcium and potassium in plants. Only recently have workers expressed in the literature the plant composition of cations on an equivalent basis. This method is preferred in a discussion of cations to that of using a percentage basis. Plant composition expressed in percentages tends to minimize the variation in magnesium. It also accentuates the variation in potassium since the equivalent weight of magnesium in comparison to hydrogen is 12, potassium 39,

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[3]Figures in parenthesis refer to "Literature Cited", p. 895.

and calcium 20. It would require three times as much potassium as magnesium on a weight basis to compare to a similar change in equivalency, and nearly twice as much as for calcium. Since potassium is so easily absorbed and can upset the function of calcium and magnesium, the use of excessive amounts of potassium fertilizers, where the calcium and magnesium supply is not adequate, results in what is often called "luxury consumption".

SODIUM AS A PLANT CATION

One of the more enlightening papers on the equilibria of cations has been reported by a Dutch worker, Van Itallie (16), who showed that the sum of the four cations, Ca, Mg, K, and Na, in the dry material of Italian rye grass remained approximately constant. This occurred even though there existed large variations for each cation in the plant, because the soil received various amounts of cations. In his results, 14 values out of 22 had a deviation of only 5 m.e. from a total average of 200 m.e. per 100 grams. The figures shown in Table 1 are from a portion of his data which illustrate these cation equilibria. From these results it would appear that sodium can perform some of the functions which are common to the other three cations, especially potassium.

Harmer and Benne (7) in a report on the use of salt on organic soils showed that some crops, such as celery, table beets, and sugar beets, are responsive to the addition of sodium. In such crops, the sodium content in the plant is greatly increased by the addition of sodium to the soil, and the potassium is decreased considerably and magnesium and calcium slightly. The total cations in sugar beet leaves and celery were also shown to be nearly uniform. The summary of their results are similar to those illustrated in Table 1. Holt and Volk (8) also report that for some plants sodium may be an essential nutrient for maximum growth, and that sodium can be substituted for potassium to a variable extent, depending on the kind of plant. In a recent paper, Sayre and Vittum (14) report that sodium can be substituted to a limited extent where the potassium supply is not adequate, but for soybeans adequate potash was better than any

TABLE 1.—*Exchangeable cations in soil and cation content of Italian rye grass grown thereon in a pot experiment.**

Yield, grams per pot	Cations present in 100 grams of grass, dry weight					Exchangeable cations present in 100 grams of soil			
	Ca	Mg	Na	K	Total	Ca	Mg	Na	K
9.8	17.0	24.0	11.5	134	186	6.7	1.1	0.3	0.4
8.5	35.5	26.5	12.5	129	203	13.7	1.1	0.3	0.4
5.0	39.0	25.5	12.0	124	200	20.7	1.1	0.3	0.4
8.0	14.0	49.0	9.5	123	196	6.7	8.1	0.3	0.4
7.8	11.5	62.5	9.0	112	195	6.7	15.1	0.3	0.4
5.8	8.0	17.5	97.0	78	201	6.7	1.1	7.3	0.4
5.5	8.0	17.5	13.0	169	208	6.7	1.1	0.3	7.4

*Data from Van Itallie (16).

partial sodium substitution. In general, sodium is not absorbed in very large amounts by plants growing in the humid areas of the United States. It has been mentioned just to indicate that it may be a factor in cation balances.

CATION EQUIVALENT CONSTANCY

In earlier work, it has been shown (10) that the total equivalents of the bases in legumes tended to be constant. Bear and Prince (4), in a more detailed experiment, showed similar relationships for alfalfa. The data shown in Table 2 for alsike illustrates this tendency. These analyses were made on plant samples collected from field plots growing in three soil regions in Indiana. The calcium content in these plants was found to vary between 52 to 81 m.e. per 100 grams of air dry material, magnesium between 18 to 45 m.e., and potassium between 22 to 56 m.e. The total bases varied between 124 to 148 m.e. which is a smaller variation than for each carion singly.

TABLE 2.—*Comparison between the cations in alsike (air-dry basis) and the exchangeable cations in the soil on which the plants were grown from data by Lucas, Scarseth, and Sieling (9).*

Treatment	Yield of mixed hay, lbs. per acre	Cations in plants in m.e. per 100 grams, dry weight				Exchange cations in soil, m.e. per 100 grams			
		Ca	Mg	K	Total	% base saturation	Ca	Mg	K
				Bedford Silt Loam					
None	420	64	27	49	140	57	4.7	0.74	0.15
NPK	1,990	70	28	31	129	56	5.2	0.60	0.15
L-NPK	2,560	78	27	27	132	78	8.8	0.45	0.14
L-M-MPK	3,170	71	27	38	136	74	8.3	0.60	0.19
Heavy fertilization	4,430	52	18	56	126	65	5.4	0.55	0.29
				Clermont Silt Loam					
None	960	56	27	41	124	47	3.5	0.99	0.13
NPK	2,450	52	27	45	124	41	3.0	0.70	0.14
L-NPK	3,440	70	34	26	130	74	6.4	1.08	0.11
				Crosly Silt Loam					
None	3,520	81	45	22	148	73	8.7	2.50	0.13
Residue N-PK	5,750	64	36	29	129	72	8.7	2.36	0.15

Not all investigators have observed the effect of cation constancy. Mehlich and Reed (12) found greater uptake of Ca, Mg, and K in cotton at higher degrees of Ca saturation even though reciprocal relationships were observed. The data in Table 3 show that cotton plants grown in soils of low Ca saturation and high K levels absorbed only 60 m.e. of bases. Soils of high Ca saturation and low K caused the plants to absorb 140 m.e. per 100 grams of material. It will be noted that increasing the level of K for any given percentage saturation of calcium caused a lowering of the Ca and Mg contents. In results

similar to these, one should consider the molecular ratio $\frac{Ca+Mg}{K}$ for many potash deficiencies in plants have been associated with wide ratios. If this be true, then the results well illustrate the need for more potash at higher calcium levels. The results of Albrecht and Schroeder (1) also indicate that a sum-total cation absorption constancy does not exist. They obtained greater total cation absorption per unit weight of spinach at higher levels of calcium.

TABLE 3.—*The effect of various levels of K and Ca in the soil upon the cations absorbed by cotton.**

Percentage calcium saturation in soil	Average K level of soil, m.e.	Cations in plants, m.e. per 100 grams				Plants ratio Ca+Mg†
		K	Mg	Ca	Total	K
20	0.025	6.9	15.7	51.0	74	9.6
	0.040	9.1	12.0	46.0	57	6.4
	0.080	13.3	6.8	40.0	60	3.6
40	0.025	7.5	19.4	89.5	116	13.5
	0.040	11.7	15.9	79.0	107	7.8
	0.080	19.4	12.8	72.0	104	4.2
60	0.025	8.0	19.6	110.5	140	16.5
	0.040	12.7	16.6	101.0	130	9.0
	0.080	18.4	14.1	77.5	110	5.1

*Data from Mehlich and Reed (12).
†Data calculated by Lucas and Scarseth.

By converting the data obtained by Naftel (13) from percentages to equivalents, it was possible to show some interesting effects of soil types, percentage base saturation, and $MgCO_3$ vs. $CaCO_3$ on the cation content of sorghum. These results are shown in Table 4. Although one soil was a clay loam and the other two sandy loams, the total intake of bases were nearly uniform at levels of high percentage base saturation. In these data one can show the effect of the addition of $MgCO_3$ on plant composition. The mutual replacement of the calcium by magnesium is more pronounced than the replacement of potassium.

In view of the results of these and other investigators, it can be shown that some crops do not exhibit a cation absorption constancy, especially under experimental conditions where various factors are controlled and compared. Under field conditions where it is not possible to interpret the various deviations from the controlled factors, one could point out a reasonable high tendency for basic cation absorption constancy for crops high in bases.

RELATIONSHIP BETWEEN CATIONS IN SOILS AND IN PLANTS

Using a formula proposed by Bray (3), Mehlich (11) was able to point out a reasonable correlation between the soil analyses and plant

TABLE 4.—*Cation content of sorghum grown in a greenhouse experiment on soils with varying base saturations from $CaCO_3$ and $MgCO_3$.**

Saturation, %	Cation content in m.e. per 100 grams dry weight in plants on											
	Decatur clay loam				Hartsell sandy loam				Norfolk sandy loam			
	Ca	Mg	K	Total	Ca	Mg	K	Total	Ca	Mg	K	Total
					Native							
—	29	16	29	74	35	11	15	61	40	21	9	70
					$CaCO_3$							
50	31	16	29	76	40	11	12	63	52	18	8	78
75	33	14	27	74	49	9	12	70	58	18	7	83
100	37	13	25	75	61	8	12	81	66	8	7	81
125	39	13	23	75	64	6	10	80	68	8	—	—
					$MgCO_3$							
50	27	22	27	76	39	39	13	91	27	45	7	79
75	26	31	24	81	36	43	10	89	21	58	4	83

*Data from Naftel (13).

analyses from data by Mehlick and Reed (12), shown in Table 3. The following equation for calcium in the plant, as an example, illustrates this relationship:

$$\text{Calcium in plant} = \frac{Ca}{Ca(C_{Ca}) + Mg(C_{Mg}) + K(C_K)} E.$$

The values of Ca, Mg, and K are the m.e. of exchangeable ions in the soil. C_{Ca}, C_{Mg}, and C_K are coefficients of absorption by plants and "E" is the amount of cations which are found in the plants. Mehlich calculated that the coefficient of absorption of cations in relation to calcium for data shown in Table 3 was $C_{Ca}=1$, $C_{Mg}=3.3$, and $C_K=21$. As he pointed out, there are other factors than those shown in the formula which modify the cation absorption in plants, such as the ratio between exchangeable hydrogen and the exchangeable basic cations, the total cation absorption capacity of the soil, and the type of clay.

The use of salts, as potash or magnesium sulfate, in band application would no doubt destroy the validity of the formula since the electrostatic forces on the clay would have less opportunity to enter into competition with the plant root for obtaining the cations. Since each plant species has a different genetic make-up, the coefficient value would vary for different plants. The formula, nevertheless, brings out the fact that the K content in plants is affected by the ratio of exchangeable Ca and Mg in the soil. For this reason, a measure of K cannot be evaluated adequately unless the Ca and Mg content of the soil are known.

Jenny and Ayres (9) observed that the proportion of the exchangeable K available for barley roots increased with the percentage K

saturation of the clay system used. Since it takes a greater amount of K to bring a soil with a high exchange capacity to a given percentage saturation than it does a soil with a low capacity, the same response might not be expected from a given rate of potash application used on different soils with widely varying amounts of total exchangeable Ca, Mg, and H.

CATION BALANCE

When some data by Boynton and Burrell (5) on the effect of potassium fertilization on the cation composition of apple trees are calculated on a chemical equivalent basis (Table 5), it is strikingly revealed that the contents of calcium and magnesium are consistently changed. Applications of potassium to the soil increased the potassium content of the leaves but lowered that of the calcium and magnesium. A similar change was noted in the exchangeable cations of the soil.

TABLE 5.—*Apparent effect of potash fertilization on analysis of leaves from McIntosh trees and analysis of soil (0 to 8 inch depth) under the trees.**

Treatment	Pair No.	Leaf analysis, m.e. per 100 grams†				pH	Exchangeable cations		
		Ca	Mg	K	Total		Ca	Mg	K
+K	1	73	12	37	122	4.5	2.95	0.13	0.21
Check		84	28	19	131	5.0	3.21	0.19	0.04
+K	3	74	15	30	119	4.4	2.08	0.08	0.48
Check		90	35	14	139	4.9	3.53	0.23	0.08
+K	5	62	9	37	107	4.5	2.10	0.11	0.30
Check		90	18	25	133	4.7	2.35	0.19	0.07
+K	7	67	9	33	109	4.1	2.26	0.11	0.40
Check		94	26	20	140	4.3	1.86	0.26	0.10
Average of 9 pairs:									
+K		67	11	35	113	4.4	2.40	0.14	0.34
Check		88	28	18	134	4.7	2.67	0.25	0.12

*Data from Boynton and Burrell (5).
†Data calculated to m.e. from percentage composition.

In a study reported by Allaway and Pierre (2), and later by Stanford, *et al.* (15), it was shown that corn grown on unproductive high-lime soils in Iowa responded markedly to potash applications even though 140 to 200 pounds per plow layer acre of exchangeable K were present. It was concluded that the poor growth of corn was due largely to a failure of the plant to absorb adequate amounts of potassium because of an unfavorable balance between cations within the plant as well as in the soil. The application of potash to the soil permitted the plants to utilize more potassium which decreased the absorption of calcium and magnesium per unit weight of plant. The data shown in Table 6 are their analyses on plant samples collected 30 to 45 days after treatment. The results showing the total amounts of cations absorbed do not substantiate the supposition that the equiva-

lents of bases in corn tend to be constant, nevertheless, they well illustrate the reciprocal effect of the cations. In each of the three fields the addition of 200 pounds per acre of potash increased the K content considerably and decreased the total equivalents of Ca and Mg in about the same amount.

TABLE 6.—*Cations in corn plants that were normal or showed potassium deficiency.**

Treatment, lbs. per acre	Average m.e. per 100 grams, dry weight				$\frac{Ca+Mg}{K}$ ratio
	K	Ca	Mg	Total	
Holdgrafer Field					
None (deficient)....	19.9	43.4	76.3	140	6.0
100 potash.........	31.9	34.2	59.4	126	2.9
200 potash.........	38.1	29.6	67.4	136	2.6
Normal plants......	31.2	25.9	51.0	108	2.5
Stone Field					
None (deficient)....	14.9	33.4	68.3	117	6.8
200 potash.........	26.4	25.0	39.5	91	2.5
Normal plants......	35.6	20.5	33.7	90	1.5
Warland Field					
None (deficient)....	14.8	32.9	58.5	106	6.1
100 potash.........	22.5	24.0	54.5	101	3.5
200 potash.........	28.4	17.0	53.5	99	2.5
Normal plamts.....	18.9	19.5	48.5	87	3.6

*Samples collected July 29 and 30. Data from Stanford, Kelly, and Pierre (14).

As a result of their investigations, Stanford, *et al.* (15) place emphasis on the $\frac{Ca + Mg}{K}$ balance. A comparison between analyses of the potassium-deficient plants grown on one soil (the Holdgrofer field) and the normal plants grown on another soil (the Warland field) support this reasoning, since the amount of potassium in the plants from both soils was practically the same. The sum of the Ca and Mg in the potassium-deficient plants was 120 m.e. and that of the normal plants only 68 m.e., but the ratio of $\frac{Ca + Mg}{K}$ decreased from 6.0 to 3.6. Similar results from data shown in Table 7 were obtained by Lucas, *et al.* (10) from a study of the cation composition of mature corn stover. Corn from the unfertilized Crosby silt loam (check plot) showed extreme potash deficiency. The wide $\frac{Ca + Mg}{K}$ ratio of 7.2 in the stover would suggest such a deficiency. The ratio in the plants harvested from the "residue-fertilized" plot on the Crosby soil also indicated that the potash was low and probably inadequate in spite of the large yield. The higher level of available phosphorus and nitrogen had caused a drain on the potash supply. The cation ratio for stover

on this plot was 4.3. A comparison between the fertilized and lime-fertilized plots shows that the addition of lime increased the $\frac{Ca + Mg}{K}$ ratio from 2.0 to 2.6 on the Bedford soil and from 1.3 to 2.2 on the Clermont soil. Much of the changes in ratio, however, would have to be charged to increased consumption of potassium by the larger crop rather than to the Ca-K ratio of the soil. There was no visible evidence of potash deficiency on any of the corn grown on the Bedford and Clermont soils. A $\frac{Ca + Mg}{K}$ in the corn plant of less than 3.5, as suggested by Stanford, *et al.* (15), would probably indicate an adequate level of K. Excessive consumption of K as shown for the corn stover from the "heavy fertilized" plot illustrates the unprofitable practice of using excessive amounts of potash. Bear and Prince (4) suggest that the K content of alfalfa plants should exceed 1% in order to prevent a deficiency. Assuming from their results that the average total cation content is 175 m.e. per 100 grams, the $\frac{Ca + Mg}{K}$ ratio should then be less than 3.5 for alfalfa. Analyses of red and alsike clovers (10) indicate similar values.

TABLE 7.—*Cation content of mature corn stover as affected by soil type and soil treatment calculated on air-dry weight basis.**

Soil treatment	pH	Yield, bu. per acre	Cation content, m.e. per 100 grams, dry weight				$\frac{Ca+Mg}{K}$
			K	Ca	Mg	Total	
Bedford Silt Loam							
None	5.7	17	26	19	31	76	1.9
NPK	5.7	38	24	20	28	72	2.0
L-NPK	6.7	44	20	24	28	72	2.6
L-NI-NPK	6.5	60	37	23	23	83	1.2
Heavy fertilization	5.9	53	43	20	15	80	0.9
Clermont Silt Loam							
None	4.8	24	21	13	22	56	1.7
NPK	4.7	46	25	16	16	57	1.3
L-NPK	5.7	66	21	21	26	68	2.2
Crosby Silt Loam							
None	5.9	50	11	23	56	90	7.2
Res.-NPK	5.9	98	15	23	41	79	4.3

*Data by Lucas, *et al.* (10). See Table 2 for approximate soil analysis.

AGRONOMIC CONSIDERATIONS

In an overall consideration of cation balances in soils and plants, the following general recommendations are suggested: Lime the soil so that about 75% of the exchange capacity is saturated with bases.

This means that the pH of the soil would be about 6.0 to 6.5. The use of some dolomitic limestone is advisable if magnesium is suspected to be low. Soils where Mg deficiency most likely will occur are those low in exchange capacity which received calcic limestone or large applications of potash. On the acid sandy soils where the pH must be held low as for potatoes, magnesium should be added in some neutral salt, which is a common practice in some areas.

The problem of potash fertilization is rather difficult to express in simple terms because of its ease of absorption by plants and its low content in many soils of humid areas. From the results obtained on three silt loams in Indiana (10), where erosion losses were not great, the average yearly amount of potash contributed by the soil to the plants varied between 20 to 30 pounds per acre. These results were obtained where the rotation was corn, soybeans, wheat, and hay. For the management of such soils, the amount of potash to be added to the soil would roughly be the difference between the sum of the potash required by the crop and the amount contributed by the soil. Soils with high Ca and Mg contents would need larger initial applications of potash in order to build up a sufficient potential to counteract the Ca and Mg. For this reason muck soils need large initial applications of potash. The inherent fertility of the soil should, of course, always be considered. Sandy soils and muck soils are naturally low in potash-bearing minerals. Leaching losses are greater in sandy soils.

The over-use of potash is the exception rather than the general rule. One might find too high a level of potash in soils of greenhouses, gardens, and truck crops. A marked deficiency of magnesium has been observed by the authors in tomatoes grown in the greenhouse because of large potash applications. In general, a knowledge of the requirements of nutrients by the particular crop grown would aid one in calculating potash needs. Periodic plants and oil tests are always a helpful tool in guiding one attempting to maintain a balance of the cation contents in plants.

SUMMARY

The reciprocal relationship of the principal basic cations of plant nutrition are discussed. Data from various sources are used to show that the content of either calcium, magnesium, or potassium reflect the status of the other cations and how this information has practical agronomic applications.

LITERATURE CITED

1. ALBRECHT, W. A., and SCHROEDER, R. A. Plant nutrition and the hydrogen ion. Soil Sci., 52:313–327. 1942.
2. ALLAWAY, H., and PIERRE, W. H. Availability, fixation, and liberation of potassium in high-lime soils. Jour. Amer. Soc. Agron., 31:940–953. 1939.
3. BRAY, R. H. Ionic competition in base exchange reactions. Jour. Amer. Chem. Soc., 64:954–963. 1942.
4. BEAR, F. E., and PRINCE, A. J. Cation-equivalent constancy in alfalfa. Jour. Amer. Soc. Agron., 37:217–222. 1945.
5. BOYNTON, D., and BURRELL, A. B. Potassium: Induced magnesium deficiency in the McIntosh apple tree. Soil Sci., 58:441–454. 1944.

6. EHRENBERG, P. Das Kalk-Kali Gesetz. Landw. Jahrb., 54:159. 1919. (Abs. in Exp. Sta. Rec., 47:818. 1922.)
7. HARMER, P. M., and BENNE, E. J. Sodium as a crop nutrient. Soil Sci., 60: 137–148. 1945.
8. HOLT, M. E., and VOLK, N. J. Sodium as a plant nutrient and a substitute for potash. Jour. Amer. Soc. Agron., 37:821–827. 1945.
9. JENNY, H., and AYRES, A. D. The influence of the degree of saturation of soil colloids on the nutrient intake by roots. Soil Sci., 48:443–459. 1939.
10. LUCAS, R. E., SCARSETH, G. D., and SIELING, D. H. Soil fertility level as it influences plant-nutrient composition and consumption. Purdue Univ. Agr. Exp. Sta. Bul. 468. 1942.
11. MEHLICH, A. Soil properties affecting the proportionate amounts of Ca, Mg, and K in plants and in HCl extracts. Soil Sci., 62:393–409. 1946.
12. ———— and REED, J. F. The influence of the degree of saturation, K level, and Ca addition on removal of Ca, Mg, and K. Soil Sci. Soc. Amer. Proc., 10:87–93. 1946.
13. NAFTEL, J. A. The influence of lime on yields and on the chemical composition of plants. Jour. Amer. Soc. Agron., 29:537–547. 1937.
14. SAYRE, C. B., and VITTUM, M. T. Substitution of sodium for part of the potassium in mixed fertilizers. Jour. Amer. Soc. Agron., 39:153–161. 1947.
15. STANFORD, G., KELLY, J. B., and PIERRE, W. H. Cation balance in corn grown on high-lime soils in relation to K deficiency. Soil. Sci. Soc. Amer. Proc., 6:335–341. 1942.
16. VAN ITALLIE, TH. B. Cation equilibria in plants in relation to the soil. Soil Sci., 46:175–186. 1938.

Boron Response and Tolerance of Several Legumes to Borax[1]

H. T. Rogers[2]

SEVERAL factors served to stimulate boron research in the southeastern states within the last decade. Reduced emphasis on cotton and a gradual increase in legume acreages pointed up new fertility problems when some of these crops with more exacting nutrient requirements than cotton or corn were expanded to include soils of low inherent fertility.

Early work with boron on alfalfa and root crops (3, 6, 21, 29)[3] in other sections of the United States suggested the need for boron on the light-textured red and yellow podzolic soils of the Southeast if diversified crops were to be grown. Also, reports by Naftel (16) and others (14, 15), which associated over-liming injury to legumes with boron deficiency on some soils in greenhouse tests, stimulated efforts to determine how widespread these effects were in the field and to what extent this depressing effect of lime served to limit legume yields.

Probably the first report (17) that boron applications would increase seed production of crimson clover was issued in 1942. This immediately suggested the possibility of adding boron for crimson clover production in the Coastal Plains area where many disappointing failures had been experienced with this legume.

Stemming from the early work on alfalfa, it is recommended in several states that borax be included in fertilizer mixtures for this crop. The New Jersey Experiment Station (25) recommends that 5 pounds of borax be added to every ton of mixed fertilizer sold in the state. In order to find out whether recommendations of this type would be desirable in Alabama, it was necessary to determine the value of borax for a variety of legumes on the major soils of the state, as well as its residual effect and tolerance of most of the important agricultural crops to borax. All of these developments emphasized the need for more information on the boron status of the soils of the state and the boron needs of a variety of crops.

OBJECTIVES

The specific objectives of the present study were (A) to determine the need of boron fertilization for alfalfa and several important winter legumes when grown on light-textured soils and other prob-

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[3]Figures in parenthesis refer to "Literature Cited", p. 912.

lem areas where difficulty had been encountered in growing such crops, and (B) to study the tolerance of these legumes to applications of borax and minimum rates for normal growth.

The boron research of the Alabama Agricultural Experiment Station from 1942 to 1946, dealing largely with field experiments on alfalfa and several winter legumes, and correlated laboratory studies on available boron in the soil and boron in the plants, has been summarized in two parts. Reported here are the results of the field tests, showing the boron needs of a variety of legumes and preliminary work on methods of placement of borax. The second phase of the study that correlates field response with soil and plant analyses in an attempt to evaluate methods for measuring available soil boron is reported elsewhere (26).

FIELD PLOT TECHNIQUE

In all tests phosphate and potash were supplied uniformly to all plots, but the rates varied at different locations in conformity with known requirements of the soils and crops. All plots received lime, and two or more rates of lime were compared in several of the alfalfa tests. The basic rates of lime were kept as low as possible to meet the requirements of the different legumes on the various soils and at the same time to avoid over-liming effects.

The rates of borax application varied with the different legumes, ranging from 10 to 30 pounds per acre. In most of the alfalfa tests, 20 pounds of borax per acre were applied at time of seeding, while the most common rate used on the other legumes was 15 pounds per acre. Single and repeated applications of borax were made on most locations where the tests were conducted over a period of years. Most of the tests included two or more replicates and each entry in Tables 1, 2 and 3 gives the average of the several plots.

Some of the bur and crimson clover test areas were grazed during the winter and early spring. Consequently, the yields from a single clipping taken later in the spring from some of these areas appear relatively low.

The legumes tested include alfalfa, *Medicago sativa;* bur clover, *Medicago arabica;* crimson clover, *Trifolium incarnatum;* red clover, *T. pratense;* white clover, *T. repens;* Austrian winter peas, *Pisum arvense;* blue lupine, *Lupinus angustifolius;* hairy vetch, *Vicia villosa;* monantha vetch, *Vicia monantha;* soybeans, *Glycine soja;* alyce clover, *Alysicarpus vaginalis;* peanuts, *Arachis hypogaea;* and sericea, *Lespedeza cuneata.*

RESULTS AND DISCUSSION

Results reported in Tables 1, 2, and 3 show that the legumes tested fall into two groups, *viz.*, (a) those responding to borax on a high percentage of the fields, and (b) those failing to show any indication of need for application of boron.

RESPONSE BY THE MEDICAGOS—ALFALFA AND BUR CLOVER

Alfalfa produced on the average 58% more hay where borax was applied, responding on 12 of the 13 fields (Table 1). This represented an average increase of 1,807 pounds of alfalfa hay per acre per year for the addition of 20 to 30 pounds of borax at time of seeding (Table 4). A single application of borax was effective in increasing the hay yields for 2 to 3 years (Table 5). The cost of this treatment was insignificant when compared with the returns in increased hay yields. Average annual yield increases of 2 to 3 tons per acre were obtained at two locations. Very few investigators have reported responses of

TABLE 1.—*Response of alfalfa and bur clover to borax in field tests in Alabama, 1942–46.**

Location of test				Response to borax†		
County	Name of farm	Soil type‡	Duration of test, years	Increase, lb. per acre per year§	% increase	Related observations
			Alfalfa			
Lee	Main station	Norfolk l.s.	2	6,342	373	Severe alfalfa yellows and loss of stand without B
Lee	Main station	Norfolk l.s.	3	4,058	121	Residual B from 20 lbs. of borax per acre effective 3 years
Lee	Main station	Norfolk l.s.	3	3,422	68	Residual B from 20 lbs. of borax per acre effective 3 years
Baldwin	Substation	Norfolk s.l.	2	−691	−13	B-deficiency symptoms on one plot only
Lee	Main station	Madison c.l.	2	2,949	79	Rosetting and yellows without B
Lee	Main station	Chesterfield s.l.	4	1,061	14	
Escambia	State prison	Orangeburg s.l.	2	706	10	
Escambia	State prison	Orangeburg s.l.	3	410	5	
Autauga	Exp. field	Red Bay s.l.	2	1,422	18	
Pickens	Exp. field	Kalmia s.l.	1	366	6	
Chambers	Exp. field	Cecil s.l.	1	1,170	22	Severe yellows and rosetting without B
Dekalb	Substation	Hartsells f.s.l.	4	1,180	21	
Dekalb	Substation	Hartsells f.s.l.	4	1,100	25	20 lbs. of borax per acre effective for 4 years
			Bur clover			
Lee	John Capps	Norfolk l.s.	1	5,677(G)	214	Grazed during winter, failure without B (see Fig. 2)
Lee	J. D. Webster	Norfolk l.s.	1	11,350(G)	192	Poor stand, pinkish yellow leaves without B
Lee	J. D. Webster¶	Norfolk l.s.	1	7,945(G)	85	Poor stand, pinkish yellow leaves without B
Marengo	Shady Grove	Cahaba l.s.	1	8,750(G)	—	Complete failure without B (see Fig. 1)
Lee	I. J. Dorsey	Chesterfield s.l.	2	3,182(G)	67	Grazed during winter but marked response
Macon	Exp. field¶	Susquehanna c.	1	n.d.**	n.d.	No apparent response
Macon	Bledsoe-Vail	Vaiden c.l.	1	n.d.	n.d.	No apparent response
Tallapoosa	Substation	Lloyd c.l.	1	n.d.	n.d.	No apparent response
Tallapoosa	Substation	Appling c.l.	1	6,050(G)	167	Marked chlorosis without B (see Fig. 3)
Tallapoosa	Substation	Appling l.s.	1	n.d.	n.d.	Yields not taken but marked deficiency symptoms

*The field tests were conducted by various members of the Experiment Station staff during the period of 1942–46.
†Rates of borax in alfalfa varied from 20 to 30 pounds per acre at seeding; in most cases no response to annual applications.
‡Texture of soils designated: l.s. =loamy sand; s. l. =sandy loam; c. l. =clay loam; c. =clay.
§Except where designated by (G) for green weight these figures are for air-dry hay yields.
¶Giant southern bur; all other tests were on the manganese strain of southern bur clover.
**Yields were not determined.

this magnitude, even on the true podzols in the northeastern states, which are known to possess high boron-fixing capacity.

A rosetting of the terminal bud growth was frequently the first evidence of boron deficiency in alfalfa. Later, severe "yellows" accompanied by pinkish colored leaves developed with a resulting loss of stand where these severe deficiency symptoms were observed.

In view of the response to borax obtained in extensive tests (1,4, 6,7,8,9,10,11,13,28,29) in other sections of the country, it was not surprising that alfalfa showed the need for additions of boron on most of the Alabama soils tested. Aside from the root crops, alfalfa is the one crop that has shown need for applications of boron under more varied soil and climatic conditions than any other one agricultural crop. Up until the present time, this is the only field crop for which statewide recommendations for the addition of borax have been made in Alabama.

In New York, where several hundred field tests were conducted, Dawson and Gustafson (7) reported that borax applications did not increase alfalfa yields appreciably, although boron-deficiency symptoms were observed in 17% of the tests. Brown, Munsell, and King (4) reported a 21% increase in yields from five fields in Connecticut, but no increase on six other fields. Reeve, Prince, and Bear (25) recommend that 5 pounds of borax be added to every ton of mixed fertilizer sold in New Jersey, where they obtained response to borax in 12% of the 450 fields tested with various crops, including alfalfa. Dregne and Powers (8) reported increases in alfalfa yields ranging from 10 to 37% from the application of borax.

The response of alfalfa to borax suggested that bur clover, another member of the genus Medicago, might have similar boron requirements. With the exception of a reported borax response by California bur clover on some of the extremely sandy soils of Florida (12), no reports of extensive boron trials with bur clover were found.

The results of tests at 10 locations (Tables 1 and 4) show even more marked response to borax by bur clover than by alfalfa. The yield records show an average increase of 104% in green weight for the application of borax. Bur clover seedlings came up in the fall and died out where no borax was applied on at least two locations (Fig. 1). The results of these tests suggest that boron may have a role in aiding small clover seedlings to survive periods of insufficient rainfall such as occur frequently in the southeastern states during the fall months. It is believed that boron deficiency probably has accounted for many of the failures to establish bur clover as a successful green manure or pasture crop, particularly on the sandy soils of the Southeast where it appears to be adapted when properly fertilized. The application of borax to this clover is fully as important as it is to alfalfa.

Boron deficiency symptoms on bur clover are not always specific and may be confused with cold injury during the early winter months. Fig. 2 depicts severe boron deficiency of bur clover. The chlorotic leaves have a bleached appearance and frequently have a pinkish tint that eventually may become almost white. This reduction in chlorophyll content in boron-deficient leaves was quite noticeable in the bur clover samples after grinding for analysis. Powers (21) reported that

FIG. 1.—Delayed application of borax (3 months after seeding) resulted in loss of stand of bur clover on the plot in foreground, Norfolk loamy sand. Twenty pounds of borax per acre were applied to plots in background at time of seeding or before. Photograph taken March, 1944.

boron applications raised the chlorophyll content of alfalfa plants 50%.

RESPONSE BY THE TRIFOLIUMS—CRIMSON, RED, AND WHITE CLOVERS

Borax was applied to crimson clover at 19 locations, mostly in central and southern Alabama. At 10 locations where seed yields were recorded, light applications of borax produced an average increase of 259 pounds of seed per acre (Table 2). At the Main Experiment Station,

TABLE 2.—*Response of crimson, red, and white clovers to borax in field tests, in Alabama, 1942–46.*

Location of test				Response to borax*		Related observations
County	Name of farm	Soil type†	Duration of test, years	Increase, lbs. per acre per year‡	% increase	
			Crimson Clover			
Lee	Main station	Norfolk l.s.	4	760(S)	854	Seed crop practically failure without B
Lee	Main station	Norfolk l.s.	2	521(S)	362	Seed crop practically failure without B
Lee	J. D. Webster	Norfolk l.s.	1	158(S)	62	Response in seed yield but not in vegetative growth
Lee	J. D. Webster	Norfolk s.l.	1	n.d.§	n.d.	Severe injury to stand by 15 lbs. of borax per acre
Lee	John Capps	Norfolk l.s.	1	n.d.	n.d.	Early maturity and better filled seed heads
Dale	Frank Helms	Norfolk l.s.	1	−264	−16	Grazed heavily all winter
Geneva	Will Crews	Norfolk s.l.	1	604	127	Grazed heavily all winter; increased root growth where B was applied
Houston	A. B. Adams	Norfolk s.l.	1	1,029	148	Grazed heavily all winter; increased root growth where B was applied
Houston	E. V. Powers	Norfolk s.l.	1	59(S)	55	No effect on vegetative growth
Houston	J. H. McDaniel	Ruston, s.l.	1	235(S)	129	Early maturity where B was applied
Geneva	A. M. Murphy	Norfolk s.l.	1	137(S)	87	Borax decreased stand but increased seed yield
Geneva	W. K. Pullum	Orangeburg s.l.	1	117(S)	70	No effect on vegetative growth
Geneva	Fox Davis	Orangeburg s.l.	1	561	146	Grazed heavily all winter
Lee	Main station	Madison c.l.	2	135(S)	23	Response in seed yield but not in vegetative growth
Marengo	Shady Grove	Cahaba l.s.	1	194(S)	380	Also a 200% increase in straw yield
Wilcox	Henderson Bros.	Wickham l.s.	1	270(S)	415	Also a 109% increase in straw yield
Tallapoosa	Substation	Lloyd c.l.	1	n.d.	n.d.	No apparent response in vegetative growth
Dekalb	Substation	Hartsells s.l.	3	n.d.	n.d.	No apparent response in vegetative growth
			Red Clover			
Lee	Main station	Norfolk l.s.	2	566	36	Severe injury to stand by 20 lbs. of borax per acre but marked response and darker green foliage with B
Lee	Main station	Madison c.l.	2	65	2	No apparent vegetative response
Dekalb	Substation	Hartsells s.l.	1	n.d.	n.d.	No apparent vegetative response
			White Clover			
Lee	Main station	Norfolk l.s.	2	753	158	Severe injury to stand but marked response

*Rates of borax varied from 12.5 to 20 pounds per acre applied at time of seeding.
†Texture of soils designated: l. s. =loamy sand; s. l. =sandy loam; c. l. =clay loam.
‡Except where designated by (S) for seed yield, these figures refer to air-dry material from one clipping only.
§Yields were not determined.

at Auburn, on a loamy sand where seed production was nearly a complete failure without borax, a 4-year average increase of 760 pounds per acre was recorded. This increase was obtained from the average yields on 42 small plots with varying rates of lime, half of which received borax. At a number of locations borax produced no apparent effect on vegetative growth of crimson clover but increased seed production.

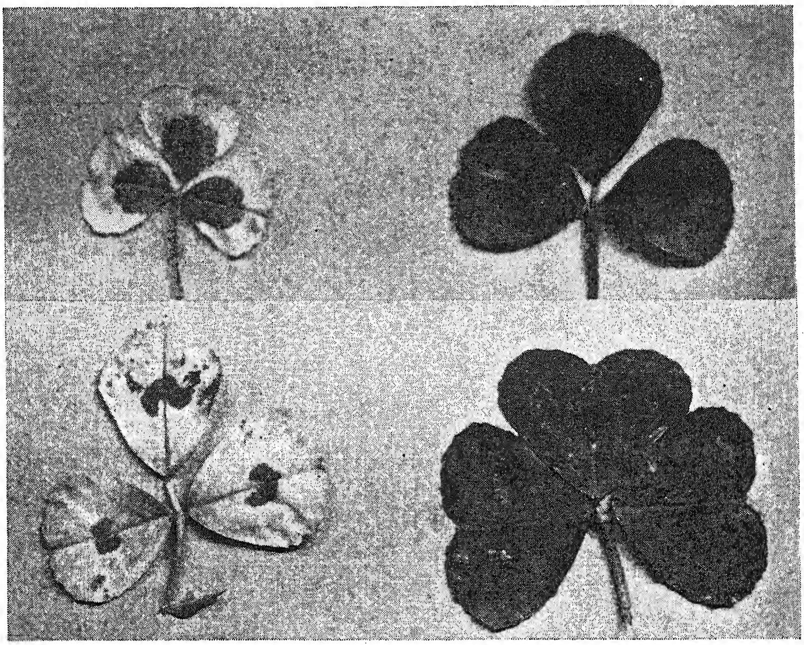

FIG. 2.—Severe boron deficiency symptoms on bur clover as shown by chlorotic leaves, *left*. Normal leaves, *right*. Top leaves are of the manganese strain and lower leaves of southern giant bur clover.

Because of the limited number of tests with red and white clovers, the results are interpreted only to indicate that these Trifoliums may benefit from an application of borax on sandy soils, if the material is applied at a light enough rate to avoid injury to stand.

VETCH SEED PRODUCTION

The value of borax for increasing vetch seed production on soils low in native boron is shown in Table 3. *Vicia monantha* and *Vicia villosa* (hairy) were each tested at two locations, giving maximum increases for the use of borax of 472 and 344 pounds of seed per acre, respectively. As noted with crimson clover, borax increased seed yields on some soils where no response in vegetative growth could be observed. At one location *monantha*, which is not as winter hardy as hairy vetch, showed less injury from cold where borax was applied.

TABLE 3.—*Response of Austrian winter peas and other legumes to borax in field tests in Alabama, 1942–46.*

Location of tests				Response to borax*		
County	Name of farm	Soil type†	Duration of test in years	Increase, lbs. per acre per year‡	% increase	Related observations
			Austrian Winter Peas			
Lee	Main station	Norfolk l.s.	2	−4,500	−20	No response and no toxicity
Lee	John Capps	Norfolk l.s.	1	−578	− 7	Severe "burning" from 20 lbs. of borax per acre
Lee	John Capps	Norfolk l.s.	1	794	21	Yields too low to be significant
Lee	L. V. Clegg	Norfolk l.s.	1	−3,366	−71	Severe injury to stand from 15 lbs. of borax per acre
Lee	John Harris	Norfolk s.l.	1	−428	−16	No response, but no injury from 10 lbs. of borax per acre
Lee	Virgil Whatley	Norfolk s.l.	1	−100	−11	No response, but no injury from 12 lbs. of borax per acre
Houston	W. E. Buie	Norfolk s.l.	1	530	27	Yields too low to be significant
Houston	C. W. Clearman	Norfolk s.l.	1	n.d.¶	n.d.	No yields taken, but no apparent response
Houston	W. E. Buie	Orangeburg s.l.	1	453	10	No significant response
Henry	J. H. Oates	Ruston s.l.	1	87	3	No significant response
Henry	J. H. Parrish	Ruston s.l.	1	n.d.	n.d.	No significant response
Lee	Main station	Madison c.l.	1	3,000	18	Possible response, but no deficiency symptoms
			Blue Lupine			
Henry	J. H. Oates	Ruston s.l.	1	436	5	Yields too low to be significant
Houston	Albert Lougue	Norfolk s.l.	1	n.d.	n.d.	Yields not taken, but no apparent response
Lee	John Capps	Norfolk l.s.	1	n.d.	n.d.	Injured by 18° cold in Dec.; no apparent response on Dec. 3, 1943
Henry	Substation	Norfolk s.l.	2	n.d.	n.d.	No apparent response

			Vetch			
Lee	Main station§	Norfolk l.s.	2	427(S)	170	Boron increased cold resistance
Lee	John Capps§	Norfolk l.s.	1	144(S)	73	Reddish-yellow foliage without B
Lee	Main station	Norfolk s.l.	1	26(S)	41	Low yields, but consistent increase from B (9 plots)
Lee	Main station	Madison c.l.	2	344(S)	38	No apparent vegetative response
			Soybeans			
Lee	Main station	Norfolk l.s.	3	609(H)	13	No significant response on soil where crimson clover failed without B
			Alyce Clover			
Lee	Main station	Norfolk l.s.	1	−846(H)	−25	B requirement very low
			Peanuts (Spanish)			
Lee	Main station	Norfolk s.l.	5	−32(S)	−2	No response
Lee	Main station	Norfolk s.l.	1	−101(S)	−7	No response
			Sericea			
Lee	Main station	Norfolk l.s.	1	−330	−12	No response and injury from annual applications

*Rate of borax varied from 10 to 20 pounds per acre.
†Texture of soil designated as follows: s. l. =sandy loam; l. s. =loamy sand; c. l. =clay loam.
‡Except where designated by (S) for seed and (H) for dry hay, these figures refer to increases or decreases in green weight.
§Vetch species was *monantha*; other tests were hairy, *villosa*.
¶Yields not determined.

The consistent and marked increases in crimson clover and vetch seed production from the addition of borax to these crops point to the need for extensive tests in the major seed-producing area of the state —the Tennessee Valley. If the Southeast as a region produces more of its legume seed requirements, a much more extensive use of boron will be needed. The possibility of boron stimulating seed production of a number of legumes which show no vegetative response should be investigated.

NONRESPONDING LEGUMES

Prior to the introduction of blue lupine in southern Alabama, Austrian winter peas was one of the major winter cover crops. Agricultural workers, however, frequently noted poor growth of this legume and the need for minor elements was suggested. In 1943 and 1944, borax tests with Austrian winter peas were put out at 12 locations, 10 of which were conducted cooperatively with farmers. Table 3 gives the results from these tests and from more limited trials with blue lupine and several other legumes.

Although some small increases in green weight were recorded, the differences are not considered significant, and without exception Austrian winter peas and blue lupine were not benefited by the addition of borax. Except for one test on Madison clay loam near Auburn, these tests were located on sandy soils where, in general, response to borax was obtained with bur clover and alfalfa.

Single tests with soybeans, alyce clover, peanuts, and sericea showed that these crops failed to benefit from borax on a soil that was severely deficient in boron for alfalfa and crimson clover.

COMPARISON OF CROPS AS TO RESPONSE TO BORAX

The various legumes that have been tested are compared as to their relative response to borax, as shown in Table 4. In the group responding to borax, the greatest average increase was obtained with crimson clover seed production and the least from red clover. It should be emphasized that, although several of the crops listed were tested at a limited number of locations, each crop was tested on one or more soils extremely low in readily soluble boron. This would indicate that the crops classified as nonresponding have extremely low boron requirements for normal vegetative growth. There is still the possibility that the seed yields of some of these legumes listed as nonresponding may be increased by the application of borax.

AMOUNTS OF BORON NEEDED

In the Alabama experiments, which were conducted on soils ranging in texture from loamy sands to clay loams, an application of 20 pounds per acre of borax produced maximum yields of alfalfa for 3 years without additional applications (Table 5). In one experiment on Hartsells fine sandy loam, 15 pounds of borax per acre applied every other year produced as much alfalfa (within experimental error) as double the rate. Two tests on Norfolk loamy sand showed that 20 pounds per acre of borax at seeding provided adequate boron for at

TABLE 4.—*Summary of the tests showing a comparison of the response by various crops to borax in Alabama, 1942–46.*

Crop	Number of locations tested		Response to borax	
	Total	Responding	Increase, lbs. per acre per year*	% increase
Alfalfa.............	13	12	1,807	58
Bur clover.........	10	7	4,773(G)	104
Crimson clover (seed)	10	10	259	244
Vetch (seed)........	4	4	247	80
Red clover†........	3	1	210	16
White clover........	1	1	753	158
Austrian winter peas	12	0	−342(G)	−4
Blue lupine.........	4	0	109	1
Peanuts (nuts)......	2	0	−67	−5
Soybeans‡.........	1	0	609	13
Alyce clover........	1	0	−846	−25
Lespedza (sericea)...	1	0	−330	−12

*Increase over no borax in pounds per acre of air-dry material except where designated by (G) for green weight of bur clover and Austrian winter peas.

†Red clover put in responding group primarily because of marked B-deficiency symptoms on one location which was corrected by the addition of borax.

‡Soybeans followed crimson clover on a soil which was highly deficient in B for the clover. Residual effects from increased clover growth would account for the slight increase in soybean hay yields.

least 2 years, and no boron deficiency symptoms were observed the third year. It was reported elsewhere (26) that the water-soluble boron in these soils, which received only a single application of borax, was the same after 2 years of cropping as that of the untreated soil. This fact substantiates the conclusion that would be drawn from the yield data in Table 5, that the amount of boron required for normal growth of alfalfa on these soils is surprisingly small.

The need for accurate information on rates of application of borax was clearly shown by a survey of the recommendations of various states which was made by Purvis (23) in 1939. The survey showed a range of several hundred per cent in the amount of boron recommended for every crop for which boron was advocated. The recommendations for alfalfa ranged from 10 to 40 pounds of borax per acre.

Recent reports show a wide range in amounts of boron recommended. Bouquet (2) advocated 50 pounds of borax per acre broadcast, or 20 to 50 pounds in the row for truck crops. On the other hand, Brown, Munsell, and King (4) reported that 20 pounds of borax per acre prevented deficiency symptoms on alfalfa 7 years after application. The tremendous variation that exists in the boron-fixing capacity of different soils was excellently demonstrated by Purvis and Hanna (22). In greenhouse tests these workers compared the effects of borax on snapbeans grown on a New Hampshire podzol and on a red and yellow podzolic soil from the Piedmont Region of South Carolina (Cecil sandy loam). A 50-pound-per-acre application of borax on the New Hampshire podzol (exchange capacity, 15.2 m.e.) failed to injure the bean crop, while 10 pounds per acre reduced the growth nearly 50% on the Cecil soil (exchange capacity, 4.1 m.e.).

TABLE 5.—*Yields of alfalfa over several years with no borax, initial application only, and initial with annual application.*

Soil type	Borax, lbs. per acre*		Yields of hay and increases for annual applications, lbs. per acre†											
			1st year		2nd year		3rd year		4th year		5th year		Average	
	Initial	Annual	Yield	Increase	Yield	Increase	Yield	Increase	Yield	Increase	Yield	Increase	Yield	Increase
Auburn Strip Test														
Norfolk loamy sand	0	0	1,905		7,200		986		—§	—	—	—	3,363	—
	20	0	2,980		10,732		8,552						7,421	
	20	10	3,069	89	10,192	−540	6,964	−1,588					6,742	−679
Auburn Bins														
Norfolk loamy sand	0	0	1,479		8,539		5,037		—§	—	—	—	5,018	
	20	0	6,270		12,807		6,245						8,440	
	30	0	6,255	−15	12,480	−327	6,487	242					8,407	−33
	20	20	5,425	−845	12,339	−468	7,075	830					8,280	−160
North Auburn Strip Test														
Madison clay loam	0	0	Reseeded test		3,919		3,525		—§	—	—	—	3,722	
	20	0			6,458		6,883						6,671	
	20	10			6,183	−275	6,747	−136					6,465	−206
Sand Mountain Substation (General Field)														
Hartsells fine sandy loam	0	0	7,040		4,860		3,810		5,000		9,180		5,978	
	15	15‡	7,780		6,590		4,330		5,830		10,720		7,050	
	30	30‡	7,930	150	7,290	700	4,370	40	5,790	−40	10,930	210	7,262	212
Sand Mountain Substation (Strip Test)														
Hartsells fine sandy loam	0	0	1,800		2,150		3,900		10,125				4,494	
	20	0	3,175		3,425		4,950		10,825				5,594	
	20	10	3,550	375	3,575	150	5,550	600	10,550	−275			5,806	212

*All plots received 1 ton of ground limestone per acre. Rate of phosphate and potash varied some at different locations but approached minimum for maintenance of stands.

†Increases or decreases in hay yields for annual application as compared with a single application of borax at time of seeding.

‡Amounts applied every other year.

§Test discontinued.

Hutcheson and Cocke (11) reported that 10 pounds of borax per acre on alfalfa at seeding increased yields for 2 years on a sandy loam in eastern Virginia. In another experiment with rates of borax application, these investigators reported maximum yields from 20 pounds per acre. New Jersey workers (25) recommend for a 2-year duration 10 pounds of borax per acre for alfalfa on light soils and 20 pounds on heavier textured soils. Washko (28) stated that 20 pounds of borax per acre on alfalfa in Tennessee would "probably be effective as long as the stand lasts". Powers (20) recommended 30 pounds of borax per acre, but reported control of deficiency symptoms from 10 pounds and injury from 40 pounds. He noted a residual effect of borax on alfalfa from 2 to 3 years after application.

Some attempts (25) have been made to interpret greenhouse results as indicative of boron needs in the field. Reports by Cook (6), Purvis and Hanna (22), Naftel (17), and greenhouse tests conducted by the writer showed that much smaller amounts of borax are needed for normal growth in pot culture than are used customarily in the field—the exact oppposite of greenhouse requirements for nitrogen, phosphorus, and potassium. Although smaller amounts of borax are needed in greenhouse cultures for normal growth, plants generally take up larger amounts of boron than the same species absorb under field conditions. Calculations which are based on uptake of boron by plants in pot cultures where luxury consumption has not been controlled obviously would not be reliable for determining the amounts of borax needed in the field.

While the cost of annual applications of borax or heavier rates applied less frequently would be insignificant, the advisability of using heavier applications of borax than are actually needed is open to question until more is known about the residual effects on other crops.

TOLERANCE OF CERTAIN LEGUMES TO BORAX

Early in the course of the field tests on sandy soils, it was found that 15 to 20 pounds of borax per acre broadcast at time of seeding would severely injure the stand of Austrian winter peas, crimson clover, red clover, and white clover if soil moisture was low at time of germination. Fig. 3 shows a field that was planted to Austrian winter peas where the stand was almost completely destroyed by the application of 15 pounds of borax broadcast at time of planting. The application of 15 to 20 pounds of borax to crimson clover severely reduced the stand on sandy soils at one or more locations in 1942, 1943, and 1944, even though these same areas were deficient in boron and responded to borax in increased seed yields. The residual boron from a 15-pound-per-acre application to crimson clover was toxic to soybeans the next summer on a loamy sand at Auburn. The clover in this test failed without borax, while soybeans which followed the clover showed a slight reduction in yield on the borax-treated plots from the borax remaining in the soil 9 months later.

The observation that applications of borax at time of seeding injured the stand of several legumes led to a study of different methods of applying borax. Some of the results of this test are given in Table 6.

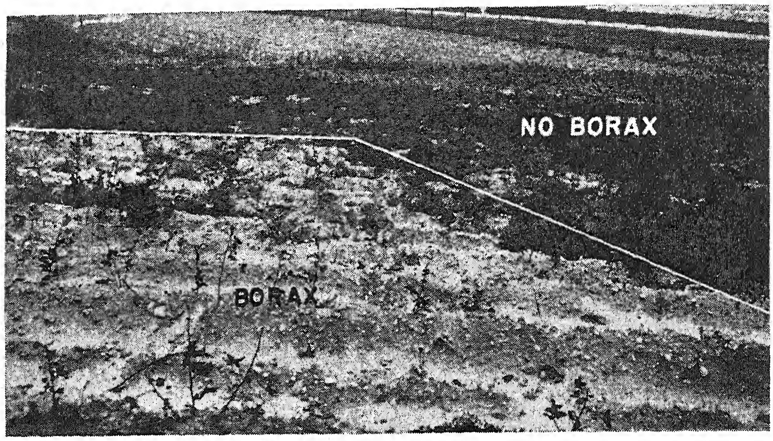

FIG. 3.—Loss of stand of Austrian winter peas from 15 pounds of borax applied broadcast at time of planting on a coarse-textured soil. Photographed February, 1943.

TABLE 6.—*Effect of time of applying borax on response and injury to winter legumes on Norfolk loamy sand.*

Treatment No.	Time and method of applying borax, 20 lbs. per acre	Green manure crops, lbs. per acre green weight		Monantha vetch for seed, lbs. per acre		Degree of toxicity§
		Austrian winter peas*	Manganese bur clover†	Straw	Seed‡	
1	No borax	8,377	2,656	3,750	197	—
2	Borax applied 4 weeks before seeding	7,818	8,281	n.d.¶	n.d.	3rd
3	Borax applied with other fertilizer at time of seeding	7,725	9,531	n.d.	n.d.	2nd
4	Borax applied ⅓ at seeding time and ⅔ 3 months later	8,563	7,187	n.d.	n.d.	4th
5	Borax applied 1 month after seeding (2 weeks after emergence)	6,422	6,250	4,000	341	1st
6	Full rate of borax applied 3 months after seeding	8,470	4,063	n.d.	n.d.	5th

*Austrian winter peas showed severe injury by treatment No. 5 about 3 months after planting. Crop was grazed off twice during winter by livestock and plot differences largely overcome by April when clippings were taken.

†Manganese bur clover was practically a failure without borax or where treatment was delayed 3 months after seeding. Seedlings came up to good stand but died during the fall months (Fig. 1).

‡Vetch showed very little or no vegetative response to borax. Treatments Nos. 1 and 5 were only ones harvested for seed.

§Crimson clover and blue lupine were included in these tests. Poor inoculation of crimson clover and winterkilling of lupine prevented reliable yield determinations of these crops. Borax had no observable effect on inoculation of clover or stand of lupine, but injured stand of clover where applied as treatments Nos. 3 or 5. Rainfall during fall months was determining factor in injury by borax to seedlings of these crops. Ranking of the several crops in December as to their susceptibility to injury by borax: Austrian winter peas>crimson clover>vetch>bur clover =lupine.

¶Yields were not determined.

Starting one month in advance of seeding, borax (20 pounds per acre) was applied at varying intervals until about 3 months after seeding. It was found that by delaying the application of borax until the seedlings were established and good soil moisture was present, injury to stands of such legumes as Austrian winter peas, vetch, and crimson clover was avoided. However, this method was not satisfactory for bur clover on soils severely deficient in boron. As shown in Fig. 2 and mentioned previously, the bur clover seedlings died after germination during dry fall months when the application of borax was delayed. It was concluded that it would be necessary on these soils which are extremely low in boron to apply borax previous to or at time of seeding bur clover. Borax (20 pounds per acre) applied prior to seeding with at least one heavy rain before seeding caused very little injury to any of the plants tested. Neither delayed application nor treatment several weeks before seeding are very practical methods. Therefore, it was concluded that the rate of borax should be kept sufficiently low to avoid injury and the borax applied with the other fertilizer materials, preferably about 2 weeks in advance of seeding. It is believed that 8 to 10 pounds per acre of borax uniformly distributed broadcast will not injure seriously any of the legumes needing additions of boron. This rate of application will probably provide sufficient boron for the Trifoliums and vetches that were studied. Bur clover and alfalfa appear much more tolerant and may require slightly heavier applications of borax.

Wallace (27) applied 5 pounds of borax in the drill row and injured velvet beans, while Purvis and Hanna (22) reduced the yield of snap beans on two sandy loam soils with 10 pounds per acre, regardless of method of applications. Piland, Ireland, and Reisenauer (19) found that 20 pounds of borax per acre reduced the stand and height of soybeans on one North Carolina soil. Nelson and Colwell (18) of the same station reported that the only soil to give response by soybeans was a fine sandy loam with high exchange capacity, which was also well supplied with exchangeable calcium and organic matter. Reeve, Eldrow, and Shive (24), working with solution cultures, found that high calcium concentration in the substrate intensified boron deficiency at low levels of boron and also decreased boron toxicity at high rates of boron application. High potassium concentrations, on the other hand, favored toxicity of boron at high levels and intensified the deficiency of boron at low levels. The smallest amount of borax which has been found to injure field crops, as reported in the literature, was obtained by Conner and Plice (5) who concluded that it was dangerous to fertilize corn in the row with more than one-half pound of borax per acre. The same investigators reported no injury to corn from 16 pounds of borax when applied broadcast.

SUMMARY

Field tests with borax at 70 crop locations included alfalfa, bur clover, crimson clover, red clover, white clover, Austrian winter peas, blue lupine, vetch, soybeans, alyce clover, peanuts, and sericea. Most of these field experiments were located on light-textured soils in cen-

tral and southern Alabama, areas where difficulty had been experienced in growing some of these legumes. Alfalfa produced on the average 58% (1,807 pounds per acre) more hay where borax was applied, responding on 12 of the 13 fields. Bur clover gave an average increase for borax of 104% and responded on 7 of the 10 locations. Crimson clover seed production was increased on all 10 areas where seed yields were recorded, with an average increase of 259 pounds of seed per acre. The group of legumes responding to borax also included vetch for seed, red clover, and white clover.

In 12 tests with Austrian winter peas, borax failed to give significant increases on a single field. Blue lupine, soybeans, alyce clover, peanuts, and sericea did not respond to borax on soils that were highly deficient in boron for alfalfa and crimson clover.

Severe injury to stands of Austrian winter peas, crimson clover, red clover, and white clover was reported on sandy soils from the application of 15 pounds of borax per acre at time of seeding these legumes. Soybeans and sericea also showed low tolerance for borax.

The boron requirement of alfalfa is extremely low when grown on the red and yellow podzolic soils of the southeastern United States. A single application of 20 pounds of borax per acre produced maximum yields of alfalfa for 3 years on sandy soils low in native boron. In some cases boron deficiency symptoms have been observed on alfalfa plants before any appreciable reduction in hay yields occurred. For this reason the most practical way to supply the boron needs of this crop may be to apply small amounts of borax annually or every other year with other fertilizers.

An application of boron at time of seeding bur clover was essential to securing a stand on two sandy soils and is rated highly important for this crop.

LITERATURE CITED

1. AHLGREN, G. H., SPRAGUE, H. B., and BEAR, F. E. Growing alfalfa in New Jersey, N. J. Agr. Exp. Sta. Bul. 718. 1945.
2. BOUQUET, A. G. B. The place of boron in growing truck. Better Crops with Plant Food, 26: No. 10. 1942.
3. BROWN, B. A. Boron deficiencies in Connecticut. Science, 91:338. 1940.
4. ————, MUNSELL, R. I., and KING, A. V. Potassium and boron fertilization of alfalfa on a few Connecticut soils. Soil Sci. Soc. Amer. Proc., 10:134–140. 1946.
5. CONNER, S. D., and PLICE, M. J. Potash and borax in fertilizers. Ind. Agr. Exp. Sta. Bul. 307. 1927.
6. COOK, R. L. Boron deficiency in Michigan soils. Soil Sci. Soc. Amer. Proc., 2:375–382. 1938.
7. DAWSON, J. E., and GUSTAFSON, A. F. A study of techniques for predicting potassium and boron requirements for alfalfa: II. Influence of borax on deficiency symptoms and the boron content of the plant and soil. Soil Sci. Soc. Amer. Proc., 10:147–149. 1946.
8. DREGNE, H. E., and POWERS, W. L. Boron fertilization of alfalfa and other legumes in Oregon. Jour. Amer. Soc. Agron., 34:902–912. 1942.
9. DUNKLEE, D. E., and MIDGLEY, A. R. Need and use of boron for alfalfa. Vt. Agr. Exp. Sta. Bul. 501. 1943.
10. HADDOCK, J. L., and VANDECAVEYE, S. C. Yield and chemical composition of alfalfa on two western Washington soil types. Soil Sci. Soc. Amer. Proc., 10:129–133. 1946.
11. HUTCHESON, T. B., and COCKE, R. P. Effects of boron on yield and duration of alfalfa. Va. Agr. Exp. Sta. Bul. 336. 1941.

12. KILLINGER, G. B., BLASER, R. E., HODGES, E. M., and STOKES, W. E. Minor elements stimulate pasture plants. Fla. Agr. Exp. Sta. Bul. 384. 1943.
13. MIDGLEY, A. R. Effects of lime and organic matter on boron fixation and availability in soils. Vt. Agr. Exp. Sta. Bul. 495. 1942.
14. ————, and DUNKLEE, D. E. The cause and nature of overliming injury. Vt. Agr. Exp. Sta. Bul. 460. 1940.
15. MUHR, G. R. Available boron as affected by soil treatment. Soil Sci. Soc. Amer. Proc., 5:220–226. 1941.
16. NAFTEL, J. A. Soil liming investigations: V. The relation of boron deficiency to over-liming injury. Jour. Amer. Soc. Agron., 29:761–771. 1937.
17. ————. Soil liming investigations: VI. Response of crimson clover to boron with and without lime on Coastal Plains soils. Jour. Amer. Soc. Agron., 34:975–985. 1942.
18. NELSON, W. L., and COLWELL, W. E. Fertilizing for better soybeans in North Carolina. Better Crops with Plant Food, 29: No. 7. 1945.
19. PILAND, J. R., IRELAND, C. F., and REISENAUER, H. M. The importance of borax in legume seed production in the South. Soil Sci., 57:75–84. 1944.
20. POWERS, W. L. Boron in relation to soil fertility in the Pacific Northwest. Soil Sci. Soc. Amer. Proc., 4:290–296. 1940.
21. ————. Boron as a fertilizer for western Oregon soils. Science, 90:36–37. 1939.
22. PURVIS, E. R., and HANNA, W. J. Boron studies: I. Susceptibility of various plants to boron toxicity as influenced by soil type. Soil Sci. Soc. Amer. Proc., 3:205–209. 1939.
23. ————. The present status of boron in American agriculture. Soil Sci. Soc. Amer. Proc., 4:316–321. 1940.
24. REEVE, ELDROW, and SHIVE, JOHN W. Potassium-boron and calcium-boron relationships in plant nutrition. Soil Sci., 57:1–14. 1944.
25. ————, PRINCE, A. L., and BEAR, F. E. The boron needs of New Jersey soils. N. J. Agr. Exp. Sta. Bul. 709. 1944.
26. ROGERS, H. T. Water-soluble boron in coarse-textured soils in relation to need of boron fertilization for legumes. Jour. Amer. Soc. Agron., 39:914–928. 1947.
27. WALLACE, R. W. Cooperative fertilizer experiments with field crops. Fla. Agr. Exp. Sta. Ann. Rpt., 1944:151. 1945.
28. WASHKO, J. B. Influence of borax and potash on alfalfa yellows. Tenn. Agr. Exp. Sta. Circ. 83. 1943.
29. WILLIS, L. G., and PILAND, J. R. A response of alfalfa to borax. Science, 86:179–180. 1937.

Water-Soluble Boron in Coarse-Textured Soils in Relation to Need of Boron Fertilization for Legumes[1]

H. T. ROGERS[2]

THE value of a soil test as a diagnostic aid in predicting response to boron is determined largely by its ability to distinguish between soils deficient in native boron and those that do not require additions of boron for normal plant growth. It would be desirable, also, that the chemical test indicate the degree of deficiency, and, as a consequence, the degree of response to be expected from boron fertilization. This accuracy in testing for a minor element such as boron, however, is not as important as in tests for the plant nutrients which are used in larger quantities.

Hot water extraction of soil was recommended by Berger and Truog (1)[3] in 1939 as a measure of the boron supply available to plants. Since that time numerous workers (5,6,9,10,11,12,17,19,23,27) have used the method, but few attempts have been made to correlate the results with field response to applications of boron. It appears that Berger and Truog (1,2) based their evaluation of the water extraction technique primarily on the fact that they found a relationship between water-soluble boron in the soil and the incidence and degree of black-spot disease of table beets on plots to which varying rates of borax had been added several months previously. Obviously, they were extracting residual borax from a soil that had been shown to be deficient in native soil boron for table beets. The fact that water-soluble boron was related to the quality of beets produced was an indirect effect of the application of varying amounts of borax. This, however, would not necessarily be evidence that water-soluble boron would be a good measure of available native soil boron on different soils where additions of boron have not been made.

Previous to the Wisconsin work, Robinson (28) in 1938 reported less water-soluble boron in unlimed orchard soils than in limed soils, although apple trees growing on the unlimed soil showed less boron-deficiency symptoms than those on the limed soil. Brown, Munsell, and King (5) reported an average alfalfa yield response of 21% over no borax on five fields, the soils of which contained 0.38 ppm water-soluble boron. On the other hand, the soil on six fields that gave no response contained 0.43 ppm boron. A report by DeTurk and Olson (10) was cited by Berger and Truog (3) as evidence that water-soluble boron is a reliable measure of available boron in soils. It should be pointed out that DeTurk and Olson (10) merely compared water-

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[3]Figures in parenthesis refer to "Literature Cited", p. 927.

soluble boron to a general productivity rating of the Illinois and Georgia soils with which they were working, which admittedly may or may not have any bearing on the boron response to be expected from these soils. The investigators pointed out that no causal effect between the productivity rating and boron supply of the soil could be claimed.

Coleman (6), on the other hand, reported data to show a good correlation between water-soluble boron in the soil and boron content of the plants on a given soil type. This relationship did not hold, however, when different soil types (similar texture) were compared. For example, he reported that cotton grown on Ruston sandy loam contained 11.5 ppm boron, with the soil showing 0.65 ppm water-soluble boron, whereas cotton on Cahaba sandy loam contained 17.5 ppm boron and the soil analyzed 0.63 ppm available boron. Although Dawson and Gustafson (9) reported water-soluble boron in the soil to be identical with "biologically available" boron (determined by sunflower cultures in the greenhouse), they failed to reconcile this conclusion with their own observation that the occurrence of boron deficiency symptoms on alfalfa in field tests showed a much better correlation with boron content of the plant than with water-soluble boron in the soil.

OBJECTIVES

The specific objectives of this study were (a) to study variations in the water extraction technique in an effort to find a method that would remove more of the boron in soils that is available to plants than is extracted by the Berger-Truog procedure, (b) to compare dilute acid extractions with the hot-water technique, and (c) to correlate the amounts of boron extracted from various untreated soils with the amounts of boron in plants and the degrees of reponse to additions of borax in field tests. The hot-water extraction technique will be evaluated from two points of view. First, the method will be examined to determine whether it will predict the degree of response of boron fertilization which can be expected on boron-deficient soils. Finally, the reliability of the test in selecting areas needing boron fertilization, without reference to degree of deficiency, will be studied.

Response to additions of boron by alfalfa and several winter legumes in terms of crop yields in a series of field tests conducted largely on coarse-textured soils in central and southern Alabama has been reported (29). The results of the correlation study in which field response is compared with water-soluble boron in the soil and plant composition are reported herein.

EXPERIMENTAL METHODS

The following hot-water extraction procedure was adopted and used in the correlation studies: Fifteen grams of screened, air-dried soil were placed in a 125-ml Florence flask (Kavalier). After adding 75 ml of distilled water and shaking for 1 hour, the flask was placed on a sand bath and connected to a reflux condenser. The soil-water suspension was boiled gently for 30 minutes and then filtered on a Buechner funnel, using specially washed No. 42 Whatman filter paper. The filtrate was poured back repeatedly until a clear extract was obtained. Boron was determined on an aliquot of this extract.

The tumeric method as outlined by Naftel (22) was used to measure boron in both soils and plants. By taking due precautions against contamination from glassware and filter paper, this method proved satisfactory for measuring small amounts of boron. Whatman filter paper No. 30 or No. 42 was found satisfactory only after washing with dilute HCl and hot water. The solids in the HCl extracts of the ashed plant material were thrown down and washed with hot water in 25-ml centrifuge tubes.

Haas (13) in 1944, reported some of the precautions necessary for accurate analyses by the tumeric procedure, pointing out the possibility of filter paper contamination. Both Florida and South Carolina workers[4] have reported difficulty from contamination by filter papers. Because of the tremendous variation in the amounts of boron contained in acid-washed filter papers, it is believed that some of the high amounts of boron reported for plants and soils may have been due to filter paper contamination. These observations suggest that before attempting to establish critical values for boron contents of either plants or soils the procedure be reviewed for possible error due to filter paper contamination.

RESULTS AND DISCUSSION

VARIATIONS IN THE WATER EXTRACTION PROCEDURE

Berger and Truog (1) reported that refluxing soil-water suspensions for longer periods than 10 minutes reduced the amount of boron extracted, although they offered no explanation for this repressive effect of longer extractions. The effect of allowing the soil-water suspensions to stand for varying periods of time before refluxing are shown in Table 1. The amounts of boron extracted from both untreated and borax-treated soils were increased greatly by cold water suspension for 48 hours or longer. Shaking the soil-water suspension for 30 minutes released as much boron from the borax-treated soil as was released by leaving the suspension standing in contact with the soil for 72 hours. The effect of shaking on boron extraction also is shown in Table 2, where data are presented on the effect of time of refluxing on amount of boron brought into solution. These data show that shaking the soil-water suspension and longer periods of refluxing than the 5 to 10 minutes recommended in the Berger-Truog method

TABLE 1.—*Effects of preliminary cold water treatment on boron extraction from soils with hot water.*

Soil	Borax treatment in the field	Boron extracted from soil (ppm) by refluxing for 8 minutes after suspension in cold water				
		0 hours	24 hours	48 hours	72 hours	30 minutes shaking
Norfolk loamy sand	10 lbs. per acre annually for 3 years	0.08	0.11	n.d.*	0.12	0.13
Norfolk sandy loam	None	0.05	n.d.	0.09	n.d.	n.d.
Orangeburg sandy loam	None	0.09	n.d.	0.20	n.d.	n.d.

*Not determined.

[4]Personal communication from W. H. Garman, South Carolina Agricultural Experiment Station, and H. W. Winsor, Florida Agricultural Experiment Station.

TABLE 2.—*Effects of shaking soil-water suspensions (cold) and time of refluxing on boron extracted.*

Soil	Borax added in the field, lbs. per acre	Boron (ppm) extracted from soil				
		Without shaking but refluxing			With shaking (1 hr.) and refluxing	
		8 min.	15 min.	30 min.	8 min.	30 min.
Madison clay loam	None	0.12	n.d.*	0.16	0.18	0.20
	20	0.26	n.d.	0.37	0.33	0.38
	40	0.65	n.d.	0.68	0.68	0.73
Vaiden clay	None	0.29	0.32	0.41	n.d.	n.d.
Orangeburg sandy loam	15	0.18	0.19	0.23	n.d.	n.d.

*Not determined.

rendered considerably more boron soluble in hot water. Shaking for 1 hour and refluxing for 30 minutes extracted more boron from both untreated and borax-treated soils than did refluxing 5 to 10 minutes. Refluxing soil-water suspensions for 8 minutes, however, gave as much spread between the highest and lowest amounts of boron extracted from the soil as did longer periods of extraction. Refluxing for periods longer than 30 minutes released very little additional boron.

Preliminary tests showed extremely small amounts of hot-water-soluble boron in most of the coarse-textured red and yellow podzolic soils. For this reason it was desirable to find a method which would extract sufficient boron that the amounts obtained would be greater than the experimental error inherent in the determination, in order to reveal any significant treatment differences. The more vigorous treatment of shaking for 1 hour and refluxing for 30 minutes was adopted because this method extracted appreciably greater amounts of boron.

WATER VERSUS DILUTE ACID EXTRACTIONS

It became obvious early in the course of the correlation studies that water-soluble boron in the soil did not bear a very close relation to the degree of response obtained in the field, particularly with soils deficient in boron for normal plant growth. Since most of the soils on which the field tests were located were low in boron, it was reasoned that possibly dilute acid extraction would be a better measure of available boron. Several modifications of Cook and Millar's (7) dilute H_2SO_4 extraction procedure were compared with hot-water extractions (Table 3.) Shaking the soil-acid suspensions and refluxing increased the amounts of boron extracted, similar to the effect of these treatments with water extraction. More boron was extracted by the acid treatments, but the amounts released failed either to correlate any better with plant response or reflect any better previous borax treatments than did the amounts of water-soluble boron (Table 4).

TABLE 3.—*A comparison of amounts of boron extracted from soil with hot water and with dilute sulfuric acid.*

Extraction procedure	Boron extracted from soil*	
	No borax, ppm	Borax applied, ppm
Soil-water suspension shaken for 1 hour and refluxed 30 minutes	0.01	0.05
Soil—0.02 N H_2SO_4 suspensions:		
Shaken 1 hour (cold)	0.02	0.04
In oven at 110° C for 10 minutes	0.04	0.05
Refluxed for 30 minutes	0.05	0.06
Shaken for 1 hour and refluxed 30 minutes	0.07	0.11

*A Norfolk loamy sand which was sampled in May, 1944, after second cutting of hay. Four cuttings were made during the year with a total increase of 3,532 pounds per acre of hay for the addition of borax which was applied at the rate of 20 pounds per acre at time of seeding in 1942.

Cook and Millar conducted extensive field tests with boron on sugar beets. After analyzing 130 soil samples from beet fields, 50% of which produced beets with heart rot, they concluded in 1939 (8) that they could find no relationship between readily soluble boron (dilute-acid extractable) in the soil and disease incidence. Whetstone, Robinson, and Byers (33) reported that normal alfalfa plants on Huntington silt loam contained 15 ppm boron as compared with 17 ppm boron in plants which showed boron deficiency symptoms and which were grown on Cecil sandy loam. The former soil contained six times as much acid-soluble (conc. H_3PO_4) boron as the Cecil soil.

A serious objection to any of the mild extractants on soils low in boron is the fact that seasonal variations in the readily soluble boron content of these soils is so great that frequently soil differences may be completely masked by the effect of time of sampling. The magnitude

TABLE 4.—*A comparison of alfalfa yields with amounts of boron extracted from the soil with water and dilute acid.**

Soil treatment		Yields of alfalfa hay, lbs. per acre		Boron (ppm) extracted from soil			
Borax, lbs. per acre†	Limestone, tons per acre	Cutting at time of sampling soil	Total for the year	Hot H_2O extraction‡		Hot H_2SO_4 extraction§	
				0–3 in.	4–7 in.	0–3 in.	4–7 in.
None	1	3,638	7,200	0.01	0.02	0.03	0.03
20	1	5,460	10,730	0.05	0.04	0.05	0.05
20(20)	1	5,355	10,192	0.08	0.11	0.09	0.10
20(20)	2	6,774	12,935	0.07	0.09	0.09	0.11
20(20)	4	5,796	10,850	0.09	0.08	0.12	0.11

*Norfolk loamy sand which was sampled in May, 1944, for this study.
†First figure indicates initial application in 1942. Figure in parenthesis is amount applied annually.
‡Soil-water suspensions were shaken 1 hour and refluxed 30 minutes.
§Cook and Millar's method: Extraction with 0.02N H_2SO_4 at 110° C for 10 minutes.

of these seasonal variations has been observed by various workers (15, 27,31,32) in noting the occurrence of deficiency symptoms during certain seasons and normal growth at other times. The first cutting of alfalfa in the spring may appear entirely normal on soils that are highly deficient in boron for maximum growth during the remainder of the season. Later in the season severe deficiency symptoms frequently will appear.

WATER-SOLUBLE BORON IN SOILS IN RELATION TO RESPONSE OF ALFALFA TO BORAX

The accuracy of any soil test is best measured by the degree of correlation between the results of the test and response to additions of the plant nutrient in question. To make this comparison, four field tests with varying rates of borax application to alfalfa were sampled during the growing season of 1945. The soil and plant samples were taken at the time of the second or third cutting when the boron level on the untreated plots is generally critical for normal growth. This was done to lessen the confusing factor of luxury consumption of the nutrient being studied, a precaution sometimes over looked. In studies where boron concentrations in the plant are to be used as an indication of the accuracy of a soil test, it is desirable to cover the range from definite deficiency through normal growth to luxury consumption. This range was covered in each of the four alfalfa tests reported in Table 5, since significant increases in hay yields ranging from 27% to 767% were obtained and the rates of borax were sufficient to produce maximum yields.

There is no apparent relationship between water-soluble boron in the surface 6 inches of soil of the untreated plots and the percentage of increase in hay yields from borax applications on the different fields. Although the range in water-soluble boron in the untreated soils was not as great as might be desirable, the soil with the smallest amount of readily soluble boron produced the least response to borax. Likewise, the amounts of boron in the tops of the alfalfa plants grown on untreated soils did not appear to be related to the water-soluble boron in the surface soil. The boron content of plants grown on the treated plots, however, did reflect the additions of borax.

A comparison of the water-soluble boron in the soil of the untreated plots and the plots that received a single application of borax showed that water extraction failed completely to pick up any residual borax in the surface 6 inches of soil from the single treatment, although in two of the four tests there was no evidence in the hay yields of the need for annual applications of boron. It is recognized that alfalfa, a plant which is normally deep-rooted, unquestionably was obtaining some of its nutrient requirements below the 6-inch depth. There is the possibility that the alfalfa was obtaining some of its boron from residual borax that had leached into the deeper horizons. Although the borax was applied to the surface of the soil, there was no evidence of a residual effect in the 3 to 6 inch layer 3 years later. The leaching and residual effects of borax are being investigated in a separate study by workers at the Alabama Agricultural Experiment Station.

TABLE 5.—*Water-soluble boron in the soil compared with boron content of alfalfa and its response to borax in the field.*

Soil type	Soil treatment		Hay yields		Boron content of soil and plants			
					H_2O-soluble B in soil		B in plants	
	Lime-stone, tons per acre	Borax, lbs. per acre*	Total for the year, lbs. per acre†	In-crease for bo-rax, %‡	1st depth, B, ppm§	2nd depth, B, ppm§	Tops, B, ppm	Crowns, B, ppm¶
Auburn—Lime and Boron Test								
Norfolk loamy sand	1	None	986	—	0.08	0.05	4.3	6.1
	1	20	8,552	767	0.08	0.08	7.3	6.9
	1	20(20)	6,964	606	0.15	0.15	12.5	6.3
	2	20(20)	11,851	—	0.10	0.13	13.5	6.9
	4	20(20)	8,195	—	0.13	0.10	11.8	7.3
Auburn—Boron Test								
Norfolk loamy sand	2	None	1,851	—	0.08	n.d.**	4.9	4.8
	2	20	7,974	331	0.07	n.d.	6.3	5.8
	2	20(20)	9,246	400	0.14	n.d.	21.5	6.3
North Auburn—Lime and Boron Test								
Madison clay loam	1	None	3,525	—	0.09	0.05	2.6	6.5
	1	20	6,883	95	0.07	0.05	5.6	6.4
	1	20(20)	6,747	91	0.11	0.21	9.9	7.7
	2	20(20)	6,822	—	0.14	0.35	10.5	7.3
	4	20(20)	7,080	—	0.33	0.43	11.0	6.9
Sand Mountain—Lime and Boron Test								
Hartsells fine sandy loam	1	None	3,900	—	0.05	n.d.	5.3	n.d.
	1	20	4,950	27	0.07	n.d.	12.3	n.d.
	1	20(10)	5,550	42	0.21	n.d.	32.0	n.d.
	2	20(10)	6,700	—	0.21	n.d.	29.8	n.d.

*First figure is initial treatment, 1942; figure in parenthesis is amount of annual application.
†Total hay yield for the year in which samples were taken. All tests were started in 1942 and samples were taken of the soil during the growing season in 1945, at least 90 days after annual applications of borax were made on the plots receiving annual treatment.
‡Per cent increase over no-borax plot.
§Depth was 0 to 6 inches in the Sand Mountain and Auburn boron tests; the 0 to 3 inch and 3 to 6 inch layers were sampled where two depths were involved.
¶Crowns included about 1 inch of stems above the ground and 2 inches of primary roots.
**Not determined.

The extremely small amounts of readily soluble boron in the soils growing normal alfalfa (those plots that had received only 20 pounds of borax per acre in 1942) indicated that either very small amounts of boron are needed for normal growth on these soils or the plants were utilizing boron that possibly had been taken up and stored in the crowns or primary roots soon after the borax was applied. Analysis of the crowns of the plants from variously treated plots on these fields showed no storage of boron. In fact, the boron content of the crowns was remarkably constant, irrespective of treatment or soil type. The obvious conclusion is that alfalfa—generally rated as having a high boron requirement—actually requires extremely small amounts of

boron for normal growth when grown on the red and yellow podzolic soils of the Southeast. These soils are low in organic matter, active calcium, exchange capacity, and boron-fixing capacity—properties that have been associated with low boron requirement. The low boron requirement of alfalfa on these soils was substantiated by the yield data reported elsewhere (29), which showed that this crop failed to respond to annual applications of borax on several of these highly leached soils for 3 years after the initial application of 20 pounds per acre at time of seeding. There was some indication that the plots getting lime at the rate of 2 tons per acre in the Auburn boron test (Table 5) needed additional boron the third year after applying 20 pounds per acre at seeding time. It should be pointed out that the use of higher rates of lime than were used in these tests probably would increase slightly the need for annual applications of borax.

It would be surprising to find a universal soil extractant which would measure accurately the boron requirement of widely different soils. Such properties as exchange capacity, organic matter content, and exchangeable calcium which exert marked effects on boron fixation and utilization must be taken into account. The comparisons thus far have shown a poor correlation between water-soluble boron in the surface soil and the degree of response obtained on soils deficient in boron. In view of the many factors involved it is not surprising that any test for available boron fails to predict the degree of response that may be obtained. The soil test for boron still may have considerable practical value, however, if it will distinguish between soils needing additional boron and those that do not require it for normal plant growth. This may be all that can be expected of any chemical soil test. The possibility of using the modified hot-water extraction procedure to differentiate between areas that will respond to boron fertilization and those which do not need additional boron will be discussed in the next section.

CRITICAL LEVELS OF BORON IN SOILS AND PLANTS FOR A VARIETY OF LEGUMES

Most of the tests thus far discussed were located on soils that had given striking response by alfalfa to boron applications. A wider range in soils as to native soil boron content and a variety of legumes were included in the tests reported in Tables 6 and 7.

Bur clover was grown on soils with a wide range in water-soluble boron content (0.03 to 0.22 ppm) and responded to a light application of borax by an average increase in yield of 104% (Table 6). When grown on soils with water-soluble boron contents ranging from 0.03 to 0.13 ppm B, crimson clover seed production was increased more consistently by boron application than any of the legumes tested. Austrian winter peas and blue lupine were not benefited by boron applications, although grown on soils of low available boron content (0.06 ppm water-soluble boron.)

The data in Table 7 and Fig. 1 show the relationship between water-soluble boron in the soil and boron content of alfalfa, bur clover, and crimson clover plants. The data are arranged in descending order of

boron content of the plants. There is only a fair correlation between the boron content of the plants and water-soluble boron in the soil when these values approach the critical levels for normal plant growth.

TABLE 6.—*Response of legumes to borax on various soils compared with the water-soluble boron content of the soils.*

Crop	Number of locations: Total	Number of locations: Responding*	H_2O-soluble B in soil, ppm: Range	H_2O-soluble B in soil, ppm: Average	Response to borax, %: Range	Response to borax, %: Average	Response to borax: Pounds per acre
Alfalfa, *Medicago sativa*	13	12	0.05–0.11	0.07	−13 to 373	58	1,807
Bur clover, *Medicago arabica*	10	7	0.03–0.22	0.09	0 to 214†	104	4,773
Crimson clover (seed), *T. incarnatum*	10	10	0.03–0.13	0.06	23 to 854	244	259
Vetch (seed), *Vicia, villosa* and *monantha*	4	4	0.05–0.09	0.07	38 to 170	80	247
Red clover, *T. pratense*	3	1	0.05–0.09	0.07	0 to 36	16	210
White clover, *T. repens*	1	1	———	0.08	———	158	753
Austrian winter peas, *Pisum arvense*	12	0	0.04–0.09	0.06	−20 to 27	−4	−342
Blue lupine, *Lupinus angustifolius*	4	0	0.05–0.10	0.06	0 to 5	1	109
Peanuts (nuts), *Arachis hypogaea*	2	0	———	n.d.‡	———	−5	−67
Soybeans, *Glycine soja*	1	0	———	0.05	———	13	609
Alyce clover, *Alysicarpus vaginalis*	1	0	———	0.05	———	−25	−846
Sericea, *Lespedeza cuneata*	1	0	———	0.05	———	−12	−330

*Locations where yields were increased significantly by borax.
†Complete failure without B on one location.
‡Not determined.

Water-soluble boron in the soil, however, does show some promise for selecting untreated areas where response to borax can be expected (Fig. 2). The three areas where no response to borax was obtained with bur clover were the only soils with more than 0.10 ppm water-soluble boron. Likewise, with one exception, all of the tests with crimson clover showed response to borax where the soil contained less than 0.10 ppm boron.

Critical levels of water-soluble boron in soils, below which the need for additions of boron is indicated for alfalfa, have ranged from 0.35 ppm boron, as suggested by Reeve, Prince, and Bear (27) for New Jersey and Dawson and Gustafson (9) for New York, to 1.00 ppm boron reported by Dregne and Powers (12) for soils of the Willamette Valley. Berger and Truog (2), however, reported 15% black heart disease of table beets where the soil contained 1.45 ppm water-soluble boron.

TABLE 7.—*Water-soluble boron in soils and boron content of plants grown thereon.*

Alfalfa		Bur clover		Crimson clover	
B in plants, ppm	B in soil, ppm	B in plants, ppm	B in soil, ppm	B in plants, ppm	B in soil, ppm
		Untreated Areas			
5.3	0.05	5.9	0.22*	11.6	0.13*
4.9	0.08	5.9	0.13*	9.7	0.05
4.3	0.08	4.8	0.11*	5.6	0.03
2.6	0.09	4.1	0.10	5.0	0.13
—	—	4.1	0.03	4.0	0.05
—	—	4.0	0.03	—	—
—	—	3.9	0.05	—	—
—	—	3.5	0.03	—	—
—	—	3.3	0.05	—	—
—	—	2.5	0.09	—	—
		Borax-treated Areas			
32.0	0.21	24.8	0.38	20.6	0.12
30.0	0.21	19.3	0.15	14.6	0.34
21.5	0.14	17.1	0.29	12.6	0.14
13.5	0.10	15.3	0.15	11.5	0.19
12.5	0.15	14.4	0.06	8.6	0.06
12.3	0.07	13.4	0.19	—	—
11.8	0.13	13.0	0.15	—	—
11.0	0.33	10.8	0.34	—	—
10.5	0.14	10.3	0.14	—	—
9.9	0.11	8.8	0.06	—	—
7.3	0.08	—	—	—	—
6.3	0.07	—	—	—	—
5.6	0.07	—	—	—	—

*The only locations where no response to borax was obtained.

Alfalfa, bur clover, or crimson clover grown on untreated soils contained less than 6.0 ppm boron in nearly every case where response to borax was obtained (Fig. 1). In 82% of the cases these plants contained more than 10 ppm boron where borax had been applied within 3 years of the time of sampling.

The following tabulation shows the range in critical values for the boron content of alfalfa plants as reported by various investigators:

McLarty, Wilcox, and Woodbridge (18)—6.9 ppm B, deficient plants.
Berger and Truog (4)—8 ppm B in deficient plants.
Haddock and Vandecaveye (14)—10 ppm B, deficient.
Powers (24)—10 ppm B, yellows.
Dregne and Powers (12)—7.0 to 11.5 ppm B, deficient alfalfa, but also normal plants contained 12 to 22.5 ppm B.
Jordan and Powers (17)—12 ppm B, deficient.
Dunklee and Midgley (11)—15 ppm B, need for boron.
Brown, Munsell, and King (5)—17 ppm B, response to boron; also 17 ppm B where no response was obtained.

Whetstone, Robinson, and Byers (33)—13 to 17 ppm B, response to boron on Cecil soil and 12 to 19 ppm B where no response was obtained on Huntington soil.

Dawson and Gustafson (9)—20 ppm B, critical level.

Munsell and Brown (21)—23 ppm B in leaves, yellows.

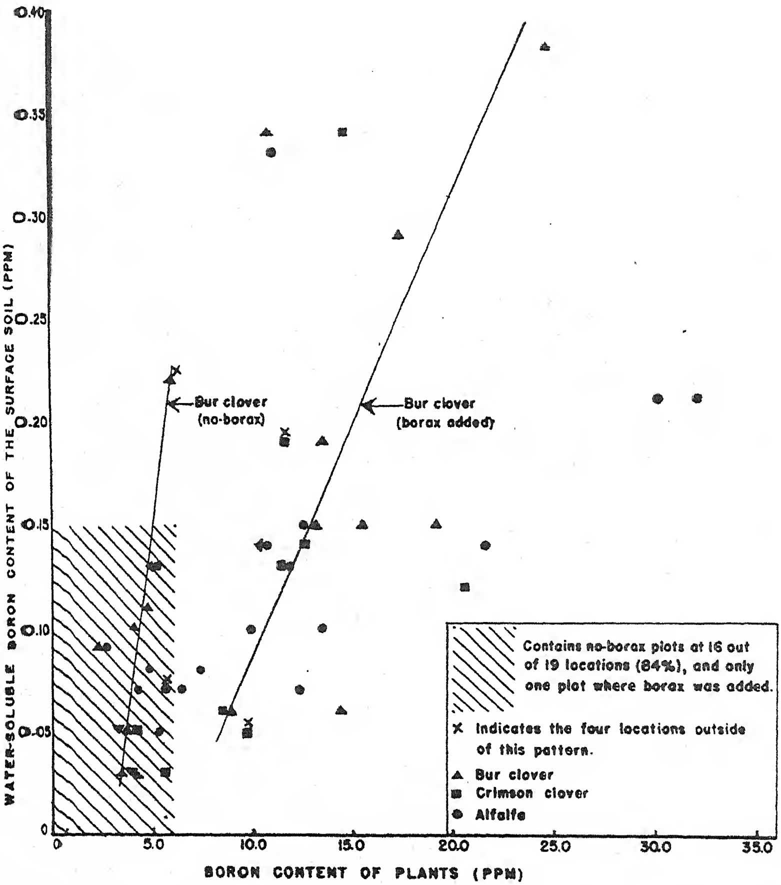

FIG. 1.—Relation between water-soluble boron content of the soil and boron content of bur clover, crimson clover, and alfalfa plants.

Allowing for border line cases, it would appear that if the soil contains less than 0.15 ppm water-soluble boron or these plants (alfalfa, crimson, and bur clover) contain less than 10 ppm boron, response to borax is indicated.

It should be emphasized that the critical levels of 0.15 ppm water-soluble boron in the soil and 10 ppm in alfalfa, bur, or crimson clover, which have been derived from the data reported herein, do not necessarily apply either to similar-textured soils of other regions or to fine-textured soils of the same region. The far-reaching effects of exchange-

able calcium, exchange capacity, and organic matter content on both boron requirement and tolerance to borax have been demonstrated by other investigators (8,16,20,25,26).

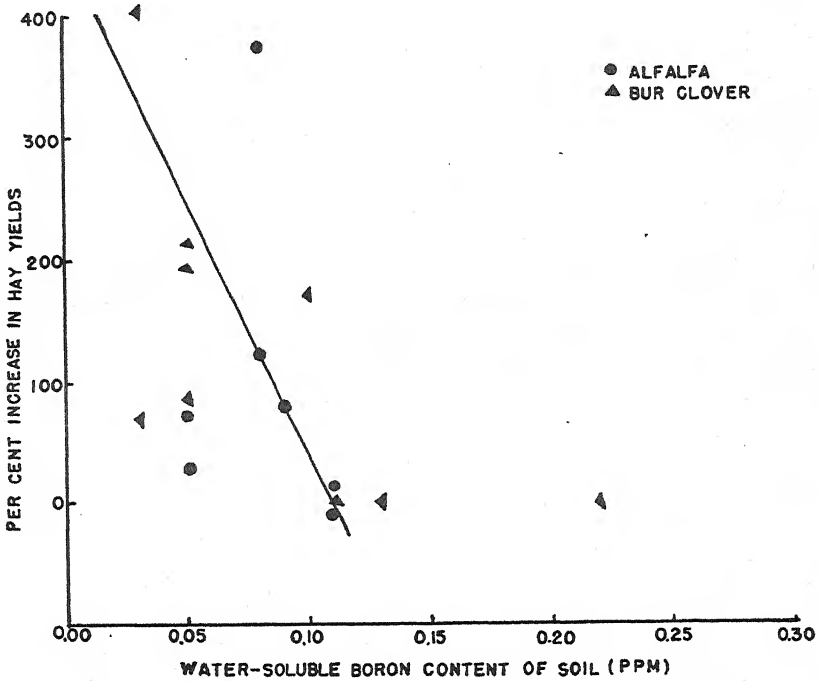

FIG. 2.—Relation between water-soluble boron in the soil and increase in hay yields from application of borax (alfalfa and bur clover).

BORON FIXATION AS MEASURED BY WATER-SOLUBLE BORON

The results of the tests reported in Table 5, which show that alfalfa required only light applications of borax for normal plant growth, suggest that these soils have low boron-fixing capacities. If water-soluble boron is an accurate measure of the available boron in soils, water extractions of soil, after incubation with additions of borax, should be a dependable method of determining boron fixation. The nature and extent of boron fixation in one of these soils (Hartsells fine sandy loam) on which alfalfa had shown a low boron requirement was investigated.

It was found (Table 8) that 34% to 44% of a 100-pound per acre application of borax to this soil was insoluble in hot water after moist incubation at room temperature for 30 days. Thirty-four per cent of the boron applied was fixed without liming the soil, and over-liming to pH 8.2 increased the fixation less than 10%. Thus, it would appear that any repressive effects of over-liming must be attributed to either the effect of calcium concentration on uptake or utilization of boron

by plants. The low boron requirement of this soil in field tests and high boron fixation in the chemical tests suggest that this boron is only temporarily insoluble and may be released gradually for plant absorption.

TABLE 8.—*Effect of soil sterilization with toluene on boron fixation.**

Treatment†	Boron added, ppm B	Boron extracted, ppm B	Boron fixed, ppm B	Percentage of added boron fixed	Soil pH after incubation
None	—	0.25	—	—	5.6
Toluene	—	0.15	—	—	5.2
Lime	—	0.20	—	—	8.1
Lime plus toluene	—	0.13	—	—	7.9
Borax	5.68	5.00	1.93	34.0	5.7
Borax + toluene	5.68	5.00	1.93	34.0	5.2
Lime + borax	5.68	4.63	2.30	40.5	8.2
Lime + borax + toluene	5.68	4.43	2.50	44.0	8.0

*Hartsells fine sandy loam which had shown good response to borax applications by alfalfa in field tests.
†Lime was added in the form of calcium hydroxide at the rate of 2 tons per acre; borax was applied at the rate of 100 pounds per acre.

As a further check on the nature of boron fixation some of the soil cultures were kept sterilized during incubation. After finding that toluene was very effective in inhibiting microbial activity in incubated soils (30), it was decided to check the effect of this sterilant on boron fixation. As shown by the data in Table 8, treating the soil with toluene either with or without additions of lime had no effect on hot water-soluble boron, thus indicating chemical rather than biological fixation.

No attempt will be made here to review the literature on overliming of soils and boron fixation, but several recent contributions should be mentioned. Although it is now generally recognized that heavy liming will increase the boron requirement of most plants on most soils, Munsell and Brown (21) reported very little effect of liming on the boron content of alfalfa, vegetables, and root crops. Reeve, Prince, and Bear (27) found no effect of lime on water-soluble boron in soils with pH values ranging from 4.5 to 7.5 although plants on limed soils responded much more to borax than on unlimed soils. Coleman (6) found that lime increased both the water-soluble boron in the soil and the boron content of plants in greenhouse cultures, while on the same soil in the field it had the exact opposite effects on both soil and plant boron.

Muhr (20), who added sucrose at the rate of 18 tons per acre to stimulate microbial activity, and Midgley and Dunklee (19), who sterilized soils by autoclaving and treatment with ether and concentrated H_2SO_4, contributed proof that boron fixation is not associated with microbial activity. The over-all evidence now appears conclusive that microorganisms are not a major factor in boron fixation.

SUMMARY

Various methods of soil extraction with hot water and dilute sulfuric acid were compared as a measure of available boron. A hot-water extraction procedure was adopted, which involves shaking the soil-water suspension for 1 hour and refluxing for 30 minutes. This procedure appeared to have practical value for selecting untreated areas where response to borax could be expected. Available boron by this method, however, failed completely to predict the degree of response that was obtained on deficient areas. Also water extractions of surface soils failed to distinguish between plots treated with borax 3 years previous to sampling which were producing maximum alfalfa yields, and the untreated plots, which were highly deficient for normal growth. These results suggest vigorous feeding of alfalfa for boron naturally present in or leached into the subsoil.

No increases in plant growth were obtained where the untreated soil contained more than 0.15 ppm hot water-soluble boron. In nearly every test untreated alfalfa, crimson clover, and bur clover plants contained less than 6.00 ppm of boron when grown on fields where response to borax was obtained. In 82% of the cases where borax had been added within 3 years the plants contained more than 10 ppm boron. If these legumes contain less than 10 ppm boron or the soil contains less than 0.15 ppm hot water-soluble boron, response to additions of borax is indicated on the coarse-textured red and yellow podzolic soils of Alabama. It was pointed out that these critical levels probably do not apply to fine-textured soils of the same region or soils of other regions that have high boron fixing capacities.

It was concluded that alfalfa, which has been rated as having a high boron requirement, actually needs very small amounts of this trace element when grown on soils with a low calcium supply and low base exchange capacity.

Sterilizing soil with toluene had no effect on boron fixation, indicating that the boron which was rendered insoluble in hot water (34% to 44% of a 100 pound per acre application of borax) was not tied up in microbial tissue.

LITERATURE CITED

1. Berger, K. C., and Truog, E. Boron determinations in soils and plants using the quinalizarin reaction. Ind. and Eng. Chem., Anal. Ed., 11:540–545. 1939.
2. ———, ———. Boron deficiencies as revealed by plant and soil tests. Jour. Amer. Soc. Agron., 32:297–301. 1940.
3. ———, ———. Boron tests and determinations for soils and plants. Soil Sci., 57:25–36. 1944.
4. ———, ———. Boron deficiencies as revealed by plant and soil tests. Amer. Fert., 91:9. 1939.
5. Brown, B. A., Munsell, R. I., and King, A. V. Potassium and boron fertilization of alfalfa on a few Connecticut soils. Soil Sci. Soc. Amer. Proc., 10:134–140. 1946.
6. Coleman, Russell. Boron content of Mississippi soils and plants. Better Crops with Plant Food, 29:No. 6. 1945.
7. Cook, R. L., and Millar, C. E. A microtitration method for determining the readily soluble boron in soils. Soil Sci. Soc. Amer. Proc., 3:146–152. 1939.
8. ———, ———. Some soil factors affecting boron availability. Soil Sci. Soc. Amer. Proc., 4:297–301. 1940.

9. DAWSON, J. E., and GUSTAFSON, A. F. A study of techniques for predicting potassium and boron requirements for alfalfa. II. Influence of borax on deficiency symptoms and the boron content of the plant and soil. Soil Sci. Soc. Amer. Proc., 10:147–149. 1946.
10. DETURK, E. E., and OLSON, L. C. Determination of boron in some soils of Illinois and Georgia. Soil Sci., 52:351–357. 1941.
11. DUNKLEE, D. E., and MIDGLEY, A. R. Need and use of boron for alfalfa. Vt. Agr. Exp. Sta. Bul. 501. 1943.
12. DREGNE, H. E., and POWERS, W. L. Boron fertilization of alfalfa and other legumes in Oregon. Jour. Amer. Soc. Agron., 34:902–912. 1942.
13. HAAS, A. R. C. The tumeric determination of water-soluble boron in soils of citrus orchards in California. Soil Sci., 58:123–137. 1944.
14. HADDOCK, J. L., and VANDECAVEYE, S. C. Yields and chemical composition of alfalfa on two western Washington soil types. Soil Sci. Soc. Amer. Proc., 10:129–133. 1946.
15. HUTCHESON, T. B., and COCKE, R. P. Effects of boron on yield and duration of alfalfa. Va. Agr. Exp. Sta. Bul. 336. 1941.
16. JONES, HAROLD E., and SCARSETH, GEORGE D. The calcium-boron balance in plants as related to boron needs. Soil Sci., 57:15–24. 1944.
17. JORDAN, J. V., and POWERS, W. L. Status of boron in Oregon soils and plant nutrition. Soil Sci. Soc. Amer. Proc., 11:324–331. 1947.
18. MCLARTY, H. R., WILCOX, J. C., and WOODBRIDGE, C. G. Yellowing of alfalfa due to boron deficiency. Sci. Agr., 17:515–517. 1937.
19. MIDGLEY, A. R., and DUNKLEE, D. E. The cause and nature of over-liming injury. Vt. Agr. Exp. Sta. Bul. 460. 1940.
20. MUHR, G. R. Available boron as affected by soil treatments. Soil Sci. Soc. Amer. Proc., 5:220–226. 1941.
21. MUNSELL, R. I., and BROWN, B. A. The boron content of certain forage and vegetable crops. Jour. Amer. Soc. Agron., 35:401–408. 1943.
22. NAFTEL, JAMES A. Colorimetric microdetermination of boron. Ind. and Eng. Chem., Anal. Ed., 11:407–409. 1939.
23. PILAND, J. R., IRELAND, C. F., and REISENAUER, H. M. The importance of borax in legume seed production in the South. Soil Sci., 57:75–84. 1944.
24. POWERS, W. L. Boron in relation to soil fertility in the Pacific Northwest. Soil Sci. Soc. Amer. Proc., 4:290–296. 1940.
25. PURVIS, E. R., and HANNA, W. J. Boron studies: I. Susceptibility of various plants to boron toxicity as influenced by soil type. Soil Sci. Soc. Amer. Proc., 3:205–209. 1939.
26. REEVE, ELDROW, and SHIVE, JOHN W. Potassium-boron and calcium-boron relationships in plant nutrition. Soil Sci., 57:1–14. 1944.
27. ————, PRINCE, A. L., and BEAR, F. E. The boron needs of New Jersey soils. N. J. Agr. Exp. Sta. Bul. 709. 1944.
28. ROBINSON, C. H. Water-soluble boron. Canada Dept. Agr., Div. Chem. Prog. Rpt. 1934–1936:15. 1938.
29. ROGERS, H. T. Boron response and tolerance of several legumes to borax. Jour. Amer. Soc. Agron., 39:897–913. 1947.
30. ————. Dephosphorylation of organic phosphorus compounds by soil catalysts. Soil Sci., 54:439–446. 1942.
31. WALKER, J. C. Histologic-pathologic effects of boron deficiency. Soil Sci., 57:51–54. 1944.
32. WASHKO, J. B. Influence of borax and potash on alfalfa yellows. Tenn. Agr. Exp. Sta. Circ. 83. 1943.
33. WHETSTONE, RICHARD R., ROBINSON, WILLIAM O., and BYERS, HORACE G. Boron distribution in soils and related data. U.S.D.A. Tech. Bul. 797. 1942.

Some Effects of Ammonium and Sodium 2,4–Dichlorophenoxyacetates on Legumes and the Rhizobium Bacteria[1]

R. E. Carlyle and John D. Thorpe[2]

RECENTLY the new herbicide 2,4-dichlorophenoxyacetic acid has come into wide use by farmers and agricultural workers. A review of the literature on this compound, commonly referred to as 2,4-D, reveals considerable information regarding its effect on certain legumes (1, 2, 3, 7, 8, 9, 10, 11, 12).[3] However, little exact information is available regarding its effect on the symbiotic nitrogen-fixing rhizobia and their relation to legumes under the influence of the herbicide. In addition most of the literature refers to the use of the 2,4-dichlorophenoxyacetic acid rather than the ammonium and sodium 2,4-dichlorophenoxyacetates which some manufacturers have recently made available. Both of these salts have the advantage of being soluble in water, which greatly simplifies the ease of application.

Field observations in Idaho and recent research by Payne and Fults (4) have revealed that 2,4-D caused growth abnormalities and reduction in nodulation in bean plants. Smith, *et al.* (5) and Stevenson and Mitchell (6) studied the effect of 2,4-D on certain soil micro-organisms, but the rhizobia were not included in these studies.

Since legumes are important in many crop rotations, the effect of applications of 2,4-D may be of considerable significance in the nitrogen economy of the soil. This is particularly true if the herbicide has a deleterious effect on all legumes and nodulation such as reported on beans by Payne and Fults (4).

The situation resolves itself into three closely related parts as far as the rhizobia and legumes are concerned, *viz.*, first, the effect of 2,4-D on the rhizobia which exist as free-living soil organisms during part of their life cycle; second, the effect of the herbicide on the legume plant itself; and third, the effect of the 2,4-D on the ability of the bacteria and the legume to form nodules.

With these questions in mind, laboratory and greenhouse studies were undertaken as follows: (A) To determine, using a synthetic medium, the concentration of ammonium and sodium 2,4-dichlorophenoxyacetates that would inhibit growth of *Rhizobium leguminosarum*, *R. phaseoli*, *R. trifolii*, *R. lupini*, *R. japonicum*, and *R. meliloti*; (B) to determine the effects of the 2,4-D salts on nodulation and growth of beans, peas, red clover, and alfalfa; and (C) to compare the effects of the ammonium 2-4,D with the effects of the sodium salt.

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[3]Figures in parenthesis refer to "Literature Cited", p. 936.

METHODS AND PROCEDURE

For the purpose of determining the effects of the 2,4-D salts on growth of the *Rhizobium* bacteria, the following medium was used; Mannitol, 15 grams; brown sugar, 5 grams; sodium ammonium phosphate, 0.25 grams; ammonium nitrate, 0.5 gram; yeast extract, 1.5 grams; magnesium sulfate, 0.05 gram; and traces of potassium chloride, and ferrous sulfate. These ingredients were dissolved in 1 liter of water. For growth of the organisms on solid media 1.5% of agar was added to the above medium. The pH was adjusted in all cases to 7.2.

The herbicides used were the ammonium and sodium 2,4-dichlorophenoxyacetates.[4] Both salts were readily soluble in the culture medium used and in water in concentrations up to 0.5 per cent.

The *Rhizobium* bacteria employed were type cultures[5] and consisted of the following: *R. leguminosarum*, *R. phaseoli*, *R. trifolii*, *R. lupini*, *R. japonicum*, and *R. meliloti*.

Serial dilutions of the 2,4-D salts, in the medium described above, were used in order to determine the point at which growth of the six *Rhizobium* species was inhibited. Growth of the organisms was also studied by streaking pure cultures on agar plates of the test medium containing different dilutions of the 2,4-D salts. The two methods checked closely and therefore only the results from the serial dilution tests are reported.

Four legumes, beans, peas, red clover, and alfalfa, were used to study the effects of the 2,4-D salts on nodulation and plant growth. The legumes were grown in 1-gallon glazed clay pots containing 8 pounds of ordinary once-washed builder's sand per pot. Before seeding, the pots containing the sand were covered with heavy wrapping paper and autoclaved for 16 hours at 15 pounds pressure. All tests were made in duplicate.

The 2,4-D treatments consisted of applications of both ammonium and sodium salts in concentrations of 0.5, 0.06 and 0.007 p.p.m. The solutions of the 2,4-D salts were added to the sand in amounts corresponding to 60% of the water-holding capacity of the sand for each pot. The pots were then weighed and maintained at constant weight for the balance of the experiment. In this way an effort was made to keep the concentration of 2,4-D in the soil water at a constant level.

The legume seeds were washed in 0.2% mercuric chloride solution, then rinsed in sterile water and seeded in the sterile sand. The red clover and alfalfa were seeded profusely and the peas and beans were seeded at the rate of 12 per pot. Each pot was inoculated with a 5-day-old pure culture of the appropriate *Rhizobium* organisms. The seeded pots were placed in the greenhouse and the legumes allowed to grow for 34 days. Crone's solution[6] was added once a week. At the end of 34 days each pot was carefully emptied, the plants removed, washed, and examined for nodulation and growth. In the case of the peas and beans, all plants were examined and nodules were counted when present. Twenty plants were chosen at random for nodule counting among the red clover and alfalfa.

RESULTS

In the 2,4-D serial dilution tests the inhibition of bacterial growth was considered to be at the point where turbidity could not be detected. Microscopic examinations revealed some growth beyond the dilution where turbidity was manifested, but it was never extensive enough to become visually apparent even after several days incuba-

[4]The ammonium and sodium 2,4-dichlorophenoxyacetates used in this study were supplied through the courtsey of the E. I. Du Pont de Nemours Co., Wilmington, Del.

[5]The *Rhizobium* bacteria used were pure cultures obtained from the American Type Culture Collection, Georgetown University Medical School, Washington, D. C.

[6]Crone's solution was made up of potassium chloride, 10 grams; calcium sulfate 2.5 grams; magnesium sulfate ($MgSO \cdot H_2O$), 2.5 grams; tricalcium phosphate, 2.5 grams; and ferric phosphate, 2.5 grams. One and one-half grams of the above stock salt mixture were dissolved in 1,000 cc of water.

tion. The six *Rhizobium* species fell into two rather widely separated groups in their ability to withstand the action of different concentrations of the 2,4-D salts (Table 1). *R. trifolii* and *R. leguminosarum* proved to be the most sensitive, growth being inhibited at a concentration of 0.03 and 0.04%, respectively, by both the ammonium and the sodium 2,4-D salts. The remaining four species were all inhibited at concentrations of about 0.3%. *R. meliloti* proved to be the least sensitive.

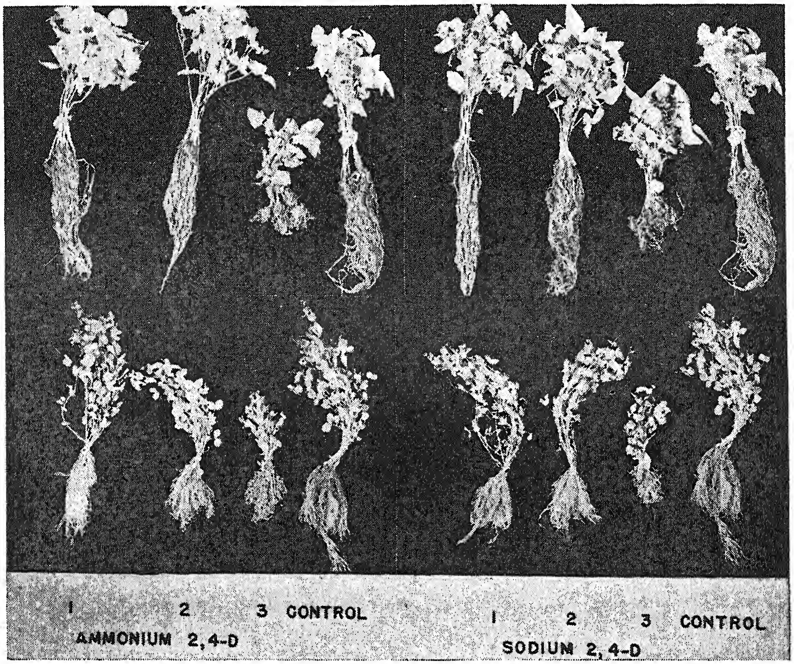

FIG. 1.—Effect of ammonium and sodium 2,4-dichlorophenoxyacetates on growth of beans (above) and peas (below). Treatments, ppm in 60% of the moisture-holding capacity of the sand, were as follows: Control, none; 1, 0.007 ppm; 2, 0.06 ppm; 3, 0.5 ppm.

The serial dilution tests gave some indication that the ammonium 2,4-D salt was slightly more toxic than the sodium salt (Table 1). When the tests were made by streaking the organisms on agar plates, the end points proved to be approximately the same as for the serial dilution tests. However, there was considerable evidence on the agar plates, as indicated by profuseness of growth, that the 2,4-D ammonium salt was more toxic than the sodium salt.

The effects of applying the ammonium and sodium 2,4-D salts to beans, peas, red clover, and alfalfa are shown in Table 2 and in Figs. 1 and 2. A concentration of 0.5 p.p.m. (in the soil solution) seriously affected both nodulation and growth of all the legumes studied. The 0.5 p.p.m. concentration caused partial inhibition of germination

in the case of red clover and alfalfa and retarded the time of germination of the beans and peas. Alfalfa proved to be particularly sensitive since a concentration of 0.5 p.p.m. of both 2,4-D salts prevented germination of over half the seeds. The red clover was not affected to the same extent but germination was partially inhibited, particularly by the 2,4-D ammonium salt. Most noteworthy was the effect of the 2,4-D salts on the root systems (Figs. 1 and 2). The 0.5 p.p.m. concentration caused extreme thickening, fasciation, and inhibition of elongation. Again the abnormalities caused by the 2,4-D ammonium salt were more pronounced than those caused by the sodium salt. The 0.06 p.p.m. concentrations did not have as pronounced an effect on the plant as the 0.5 p.p.m. concentrations, but some shortening and thickening of the root systems was clearly apparent. In practically all cases the 0.007 p.p.m. concentrations had little or no effect on growth of either the root systems or aerial parts except in the case of the beans. Here the 0.007 and 0.06 p.p.m. applications of both salts to the beans caused some stimulation of aerial growth. Accompanying this stimulation, however, was a definite chlorosis of the leaves.

The effect of the 2,4-D salts on nodulation (Table 2) was most pronounced in the case of the red clover where even a concentration

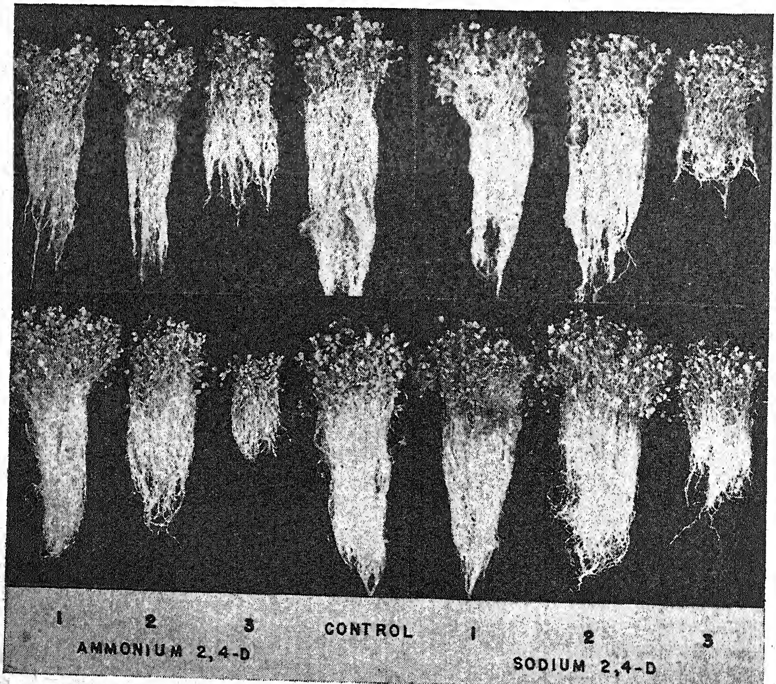

FIG. 2.—Effect of ammonium and sodium 2,4-dichlorophenoxyacetates on growth of clover and alfalfa. Treatments, ppm in 60% of the moisture-holding capacity of the sand, were as follows: Control, none; 1, 0.007 ppm; 2, 0.06 ppm; and 3, 0.5 ppm.

TABLE I.—*Effect of ammonium and sodium 2,4-dichlorophenoxyacetates on the growth of Rhizobium bacteria.**

2,4-D salt	Percentage of 2,4-D salts in medium																
	0.4	0.3	0.2	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.009	0.008	0.007	Control
R. leguminosarum																	
NH_4	–	–	–	–	–	–	–	–	–	–	+	+	++	++	++	+++	+++
Na	–	–	–	–	–	–	–	–	–	–	+	+	++	+++	+++	+++	+++
R. meliloti																	
NH_4	–	–	–	++	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Na	–	+	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
R. japonicum																	
NH_4	–	–	–	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Na	–	–	–	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
R. phaseoli																	
NH_4	–	–	–	+	+	++	++	++	++	++	++	+++	+++	+++	+++	+++	+++
Na	–	–	–	+	++	++	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
R. lupini																	
NH_4	–	–	–	+	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Na	–	–	+	+	++	++	++	++	+++	+++	+++	+++	+++	+++	+++	+++	+++
R. trifolii																	
NH_4	–	–	–	–	–	–	–	–	–	–	–	+	++	++	++	+++	+++
Na	–	–	–	–	–	–	–	–	–	–	–	+	++	++	+++	+++	+++

*+++ = Maximum growth; + = Slight growth; – = No growth.

TABLE 2.—*Some effects of the ammonium and sodium salts of 2,4-dichlorophenoxyacetates on beans, peas, red clover, and alfalfa.*

Treatment 2,4-D salt	Concentration		Average No. of nodules per plant	General plant description
	P.p.m. soil-water basis*	Lbs. per acre†		
				Beans
NH_4	0.5	0.21	13.5	Primary and secondary roots extremely shortened and thickened; aerial parts stunted
	0.06	0.03	36.7	Normal, except for reduction in nodulation
	0.007	0.003	49.1	Normal, except for reduction in nodulation
Na	0.5	0.21	25.6	Primary roots shortened; secondary root system stunted and thickened
	0.06	0.03	51.5	Normal, except for reduction in nodulation
	0.007	0.003	66.4	Normal, except for reduction in nodulation
	Control		89.9	Normal
				Peas
NH_4	0.5	0.21	13.5	Primary and secondary roots shortened and thickened; secondary roots fasciated; tips curved inward; aerial parts stunted
	0.06	0.03	28.8	Secondary roots thickened, coarse and fibrous, chlorosis of aerial parts
	0.007	0.003	33.9	Secondary roots slightly thickened; chlorosis of aerial parts
Na	0.5	0.21	0	Same as for ammonium salt but less abnormal
	0.06	0.03	21.9	Same as for ammonium salt but less abnormal
	0.007	0.003	21.1	Same as for ammonium salt but less abnormal
	Control	—	48.6	Normal
				Red Clover
NH_4	0.5	0.21	1.1	Elongation of the primary root greatly inhibited; slight thickening of the secondary roots
	0.06	0.03	0	Elongation of the primary root somewhat inhibited
	0.007	0.003	0	Normal, except for reduction in nodulation
Na	0.5	0.21	0	Primary roots considerably shortened, but not to the same extent as in the case of the ammonium salt treatment
	0.06	0.03	0	Normal, except for reduction in nodulation
	0.007	0.003	2.3	Normal, except for reduction in nodulation
	Control	—	16.7	Normal
				Alfalfa
NH_4	0.5	0.21	2.2	Root system thickened and extremely shortened; aerial parts inhibited
	0.06	0.03	3.5	Elongation of root system inhibited; primary roots thickened, secondary roots normal
	0.007	0.003	4.6	Normal, except for reduction in nodulation
Na	0.5	0.21	2.4	Root system thickened and extremely shortened; aerial parts inhibited
	0.06	0.03	4.8	Roots slightly shortened
	0.007	0.003	6.6	Normal, except for reduction in nodulation
	Control	—	6.6	Normal

*Water content equals 60% of the moisture-holding capacity.
†Acre furrow slice equals 2 million pounds.

of 0.007 p.p.m. of either salt almost completely inhibited nodulation. The 0.5 p.p.m. concentration of either salt materially reduced or completely inhibited nodulation in all cases. In general, the 2,4-D ammonium salt appeared to reduce nodulation to a greater extent than did the sodium salt except in the case of the peas where the reverse was true. Nodulation of the alfalfa plants appeared to be the least affected by the 2,4-D salts.

DISCUSSION AND CONCLUSIONS

These experiments indicate that beans, peas, red clover, and alfalfa are very sensitive to low concentrations of the ammonium and sodium 2,4-D salts in the soil solution. Since 2,4-D is seldom applied directly to legumes, an effort was made by the use of low concentrations of the salt in the soil solution to determine the possible residual effect of previous applications. Results of these experiments reveal that 2,4-D salts present in the soil solution at the rate of 0.5 p.p.m. (0.21 pound per acre) would seriously restrict germination, limit growth, and practically inhibit nodulation of these four legumes.

Some variability in sensitivity of the legumes to the herbicides was noted, but more important is the fact that the legumes studied were much more susceptible to the 2,4-D salts than were the corresponding *Rhizobium* bacteria, when considering each separately. The salts did not seriously inhibit growth of any of the rhizobia until a concentration of 0.03% was reached which would correspond to an application of 200 pounds per acre. Hence it would appear that the deleterious effect on the symbiotic relationship is apparent by a reduction or inhibition of nodulation caused largely by the action of the herbicide through the medium of the plant. However, it is also interesting to note that the greatest reduction in nodulation occurred in the peas and red clover which were inoculated with the two species of rhizobia showing the highest sensitivity to the herbicides. The results suggest that ordinary field applications of the herbicides would probably be harmful to these legume crops in that growth and nodulation would be restricted or inhibited. On the other hand, such applications would probably have very little effect on the rhizobia living free in the soil.

The stimulation of aerial growth in beans with accompanying chlorosis by low concentrations of the 2,4-D salts is worthy of comment. This effect has been corroborated by field observations where beans were planted following a crop treated with 2,4-D. Whether the effect is detrimental or beneficial could be determined by yield comparisons, but this has not been done as yet. Since 2,4-D is considered to be a plant hormone, a possible explanation is that low concentrations act as a stimulant which becomes detrimental after a certain level is reached.

No explanation is offered at this point for the difference noted between the ammonium and sodium 2,4-D salts. The more pronounced effect of the ammonium salt, however, was definite enough in most cases to discourage its use from the standpoint of the crop. The reverse might be true when considering the effect of the ammonium compound in controlling weeds.

LITERATURE CITED

1. ALLARD, R. W., DEROSE, H. R., and SWANSON, C. P. Some effects of plant growth-regulators on seed germination and seedling development. Bot. Gaz., 107:575–583. 1946.
2. HAMMER, C. L., MOULTON, J. E., and TUKEY, H. B. Effect of treating soil and seeds with 2,4-dichlorophenoxyacetic acid on germination and development of seedlings. Bot. Gaz., 107:352–361. 1946.
3. ———— and TUKEY, H. B. Selective herbicidal action of midsummer and fall application of 2,4-dichlorophenoxyacetic acid. Bot. Gaz., 106:232–245. 1944.
4. PAYNE, M. G., and FULTS, J. L. Some effects of 2,4-D, DDT, and Colorado 9 on root noludation in the common bean. Jour. Amer. Soc. Agron., 39:52–55. 1947.
5. SMITH, R. M., DAWSON, V. T., and WENZEL, M. E. The effect of certain herbicides on soil microorganisms. Soil Sci. Soc. Amer. Proc., 10:197–201. 1946.
6. STEVENSON, E. C., and MITCHELL, J. W. Bacteriostatic and bactericidal properties of 2,4-dichlorophenoxyacetic acid. Science, 101:642–644. 1945.
7. SWANSON, C. P. Histological responses of the kidney bean to acqueous sprays of 2,4-dichlorophenoxyacetic acid. Bot. Gaz., 107:522–531. 1946.
8. TAYLOR, D. L. Observations on the growth of certain plants in nutrient solutions containing synthetic growth-regulating substances. I. Some effects of 2,4-dichlorophenoxyacetic acid. Bot. Gaz., 107:597–611. 1946.
9. ————. Observations on the growth of certain plants in nutrient solutions containing synthetic growth-regulating substances. II. The influence of presentation time. Bot. Gaz., 107:611–619. 1947.
10. ————. Observations on the growth of certain plants in nutrient solutions containing synthetic growth-regulating substances. IV. The amount of growth in soil and solution cultures treated with equal weights of ammonium, 2,4-dichlorophenoxyacetate. Bot. Gaz., 107:630–632. 1946.
11. WEAVER, R. J. Effect of spray applications of 2,4-dichlorophenoxyacetic acid on subsequent growth of various parts of red kidney bean and soybean plants. Bot. Gaz., 107:532–539. 1946.
12. ————, and DEROSE, H. R. Absorption and translocation of 2,4-dichlorophenoxyacetic acid. Bot. Gaz., 107:509–521. 1946.

Note

ADDITIONAL INFORMATION CONCERNING THE INTRODUCTION OF MILO INTO THE UNITED STATES[1]

SINCE the publication of the early history[2] and of the evolution of milo in the United States, additional information has come to light concerning the introduction of the crop and how it derived its name. The late B. G. Pratt, who for many years was engaged in the manufacture of insecticides at Hackensack, N. J., and who recently died at the age of 85 has furnished the writers of this article with the following information.

The father of B. G. Pratt, the Rev. H. B. Pratt, a graduate of Princeton Seminary, went to Barranquilla, Colombia, as a missionary in 1869. The Rev. Pratt was interested in plant life and became acquainted with the numerous sorghum varieties being grown in his vicinity under the name of "Maiz Millo". There is no available information concerning the introduction of Maiz Millo into Colombia. Upon returning to the United States about 1879, he brought seed of one variety of sorghum and planted it in his garden at Winnsboro, S. C., where he was pastor of the First Presbyterian Church. As a Christmas present he wrote an advertisement for the Winnsboro *News and Herald* on "Millo Maize" and gave it to his 18-year-old son, B. G. Pratt, along with 45 pounds of seed. The seed was sold at 25 cents for 2 ounces. In 1881, B. G. Pratt rented a small piece of land to grow a seed crop and in 1882 applied for a patent on the name "Millo maize" which was granted by the Patent Office but was later revoked apparently at the instigation of J. H. Alexander, a seedsman, of Atlanta, Ga. Alexander claimed that the Millo Maize introduced by Rev. H. B. Pratt and Rural Branching Sorghum were identical varieties.

In the years immediately following the introduction of "Millo maize" by Rev. H. B. Pratt, B. G. Pratt purchased all of the "Millo maize" he could and sold it through an Atlanta, Ga., office operated by an uncle Charles Pratt. By 1885 or 1886, however, the identity of the original introduction was lost since seedsmen had been selling seed as Rural Branching Sorghum or Millo Maize, and B. G. Pratt went out of the seed business.

Apparently there can be no question but what the name "Millo maize" was originated by Rev. H. B. Pratt who anglacised the Spanish name "Maiz Millo" which means corn millet. There is, however, some question whether or not the variety brought into the United States from South America was a new variety or was actually identical to Rural Branching Sorghum. The original introduction of Rev. H. B. Pratt was a yellow variety. Within a year or two after the sale of the first "Millo Maize", Rev. H. B. Pratt sent to the same

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[1]Contribution No. 1060 from the Department of Agronomy, Texas Agricultural Experiment Station, College Station, Texas. Published with permission of the Director.

[2]KARPER, R. E., and QUINBY, J. R. The history and evolution of milo in the United States. Jour. Amer. Soc. Agron., 38:441–453. 1946.

vicinity in Colombia for more seed, but the variety he obtained was a white-seeded one that he called "White Millo Maize". This is apparently the variety that was grown at the Louisiana and Kansas Experiment Stations in 1888. A head of this variety shown in the annual report of the Kansas Experiment Station of 1889 shows it to resemble kafir and this variety was later grown as Guinea kafir. This variety is apparently extinct in the United States.

Yellow millo maize was described in a lengthy article by G. W. Benson, Marietta, Ga., that appeared in the Atlanta *Constitution* dated January 31, 1885. Benson wrote the article at the request of the editors of the *Constitution* and reported on his four years experience with "Millo maize" the seed of which he obtained from Chas. Pratt. Benson reported that "Millo maize" matured seed in 8½ months, but that he found heads in the field that matured in 5 months. These maturity dates resulted from early spring plantings, but a crop planted on oat stubble in June 1884 matured in 4½ months. This 4½-month maturity of "Millo maize" from a June planting is evidence that the variety was identical to the Giant milo grown in Texas in the 1890's and was not the Standard milo that displaced Giant milo about the turn of the century. There is no mention of dwarf plants in the crops grown by Benson and it is likely that the mutations to dwarfness in this variety occurred in the United States in later years.

The evidence indicates that the name Millo maize originated with Rev. H. B. Pratt and it seems likely that the late-maturing Giant milo grown in Texas before 1900 was the variety introduced from South America by Rev. H. B. Pratt and distributed by B. G. Pratt.

The numerous varieties of milo being grown in the United States have apparently come about as the result of using seven mutations that have occurred. G. W. Benson was able to select for earlier maturity in crops only one or two generations removed from the seed that was introduced from South America. This is an indication that the seed originally introduced was a mixture of genotypes for maturity. Under the longer days at the latitude of the southern states these maturity genotypes were able to express themselves and were made use of to result in the varieties of milo now in existence.—R. E. Karper and J. R. Quinby, *Texas Agricultural Experiment Station, College Station, Texas.*

Book Reviews

STATISTICAL ANALYSIS IN BIOLOGY

By K. Mather. New York: Interscience Publishers, Inc. Ed. 2. 267 pages, illus. 1947. $5.

THE reviewer has not seen the first edition of this work. In the preface of the second edition, the author claims that the revisions consist of various corrections and restatements to overcome certain misprints, ambiguities, and inaccuracies; also, that a chapter on transformations has been added. Since no reference to a review of the first edition in this JOURNAL has been found, it seems advisable to review the present book in its entirety. Apparently, the work is intended for those students and workers who have passed the elementary stages of statistical analysis and for this reason some topics are omitted or are given only brief mention. All through the volume the author assumes that such elements are known to the reader and therefore no explanation or discussion is given when referring to them.

Doctor Mather has crowded a wealth of statistical analysis, including the derivation of numerous equations, in the 267 pages of the book. The wide range of essential topics discussed makes it a valuable reference work as well as a manual. The analyses of many of the subjects differ from those found in many textbooks and manuals, but these unusual methods help the average worker in understanding better some of the intricate mathematics as well as giving a new viewpoint of the logic underlying some of the processes used in analyzing data. Probably the chapter on Degrees of Freedom and Analysis of Variance is the most outstanding example of the departure from the usual methods of analysis. Throughout the book the chief emphasis is placed on tests of significance, but the care to be used in planning experiments is also strongly stressed. The discussion of methods of estimation and the analysis of frequency data, while given less emphasis, is usually adequate for understanding the subjects, although, in the opinion of the reviewer, some topics might well have been given somewhat wider treatment. Perhaps the writer decided that much of this should be familiar to the reader. Most of the examples used to illustrate the various analyses throughout the book are taken from the field of genetics (the author's specialty) and for this reason the work should appeal to those biologists who are interested in plant or animal breeding. A goodly number of examples from other phases of agriculture are also given. The popularity of the earlier edition among biologists is a high commendation of the quality of the book.

A list of the chapter headings together with a summary of the sections included in each is as follows: Introductory (nature of statistics, population and samples, diagrams and graphs), Probability and Significance (simple and compound probability, agreement with hypothesis, significance), Distributions (normal, mean, and standard Deviation, fitting, skewness and kurtosis, Possion series, mean and variance of the binomial distribution), Tests of Significance (normal

deviate, t, z, X^2 and interrelations of these), Significance of Single Observations, Sums, Differences and Means, Degrees of Freedom and the Analysis of Variance, Planning Experiments (factorial, control of Error, random block and latin square, Confounding), The Interrelations of Two Variables, Polynomial and Multiple Regressions, Correlation (both interclass and intraclass), The Analysis of Frequency Data (X^2 and the normal deviate, various forms of X^2, partitioning X^2, effect of fitting a parameter, heterogeniety, 2x2, 2xj, and general contingency tables), Estimation and Information (probability and likelihood, method of maximum likelihood, inefficient statistics, simultaneous estimation, combined estimation and heterogeniety tests, planning experiments, fiducal probability), and Some Transformations (angular and probit).

A glossary of terms, four tables (c, t, X^2, and variance ratio), and an index complete the volume.—F. Z. HARTZELL.

COMMERCIAL FERTILIZERS, THEIR SOURCES AND USE

By Gilbeart H. Collings. Philadelphia: The Blakiston Company. Ed. 4. XI+522 pages, illus. 1947. $4.50.

THIS new edition contains 29 more figures, 29 more tables, and 42 more pages than the previous edition. In general, the new material represents advances in the fields of plant nutrition, fertilizer practices, and fertilizer manufacture in the period of 1941–46.

A new chapter discusses the manufacture and use of ammonium nitrate, while new sections have been added on such subjects as by-product sodium nitrate, loss of ammonia following applications of ammonium sulfate, use of urea in tobacco beds, and use of ammonium hydroxide as a fertilizer.

The chapters on superphosphates and potash have been revised, and new material has been introduced on such subjects as reversion of phosphates, metaphosphates, fixation of phosphate and potash, and new sources of potash.

Considerable new information on fertilizers carrying the "secondary essential elements"—sulfur, calcium, and magnesium—the "rarer essential elements"—iron, manganese, boron, copper, zinc, and molybdenum—and "the elements not accepted as essential for plant growth"—sodium, chlorine, silicon, aluminum, radium, and cobalt—has been added.

The sections on biological, plant-tissue, and rapid chemical tests for determining fertilizer needs of soils and crops have been expanded; as has the section on the fertilizing value of vitamines, hormones, and growth regulators.

The book contains an excellent bibliography of 606 references. Although it is considerably more valuable than the previous edition, it still contains such inaccuracies as the statement, "Firing under natural field conditions appears to be an injury resulting from drouth".
—M. T. VITTUM

Agronomic Affairs

NEWS ITEMS

DOCTOR H. K. WILSON, Vice Dean of the School of Agriculture and Head of the Department of Agronomy, Pennsylvania State College, has become head of the agricultural branch for Japan under the Supreme Command of the Allied Powers. Doctor Wilson sailed from Seattle in July and will remain in Japan for a year.

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DOCTOR L. D. BAVER, Dean of the School of Agriculture and Director of the North Carolina Agricultural Experiment Station, spent six weeks in Hawaii recently at the invitation of the Hawaiian Sugar Planters Association, advising and consulting on research work.

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PLANS are underway for the establishment of a new international periodical to be known as "Plant and Soil" to be issued toward the end of 1947 by the Martinus Nijhoff Publishing Company at The Hague. The new publication will be devoted to studies in plant nutrition, plant chemistry, and related fields of soil science, soil microbiology, and soil-borne plant diseases. Original contributions in English, French, or German are invited and should be addressed to the Secretary of the Board of Editors, Dr. E. G. Mulder, Agricultural Experiment Station, Eemskanaal ZZ 1, Groningen, Holland. The subscription price is to be $7.50 a year for a volume of approximately 400 pages (four parts).

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APPOINTMENTS in the Department of Agronomy at the University of Tennessee, Knoxville, Tenn., during 1947 include the following: Mr. Brown Beasley, formerly with the Soil Conservation Service and a graduate of the University in 1944, as Instructor of Agronomy. Mr. Elbert J. Chapman as Assistant Agronomist located at the West Tennessee Experiment Station, Jackson. Mr. Chapman received the M.S. degree from the University in June. Mr. J. K. Leasure as Assistant Professor and Associate Agronomist. Mr. Leasure received the M.S. degree from Michigan State College in December. Mr. Sam F. McMurray, a recent graduate of the University, as Assistant Agronomist. Mr. Lloyd F. Seatz, formerly a graduate student at North Carolina State College, as Assistant Professor and Associate Agronomist. Mr. Seatz spent the past summer at Bikini as a member of the Bikini Resurvey Group. Mr. L. N. Skold, formerly with the Georgia Agricultural Experiment Station, as Assistant Professor and Associate Agronomist.

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DOCTOR ULYSSES SIMPSON JONES, JR. has been appointed Associate Agronomist in the Department of Agronomy at Mississippi State College, State College, Miss. Doctor Jones recently completed his doctorate in soil chemistry at the University of Wisconsin. His work

with the Mississippi Agricultural Experiment Station will consist of research in soil chemistry and teaching in the College.

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MORRIS DALE FINKNER has recently been appointed Assistant Agronomist on the staff of the Mississippi Agricultural Experiment Station. Mr. Finkner obtained his M. S. degree at Kansas State College. His work will consist of forage and pasture crops research with the Mississippi Agricultural Experiment Station and teaching in the Agronomy Department of Mississippi State College.

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DOCTOR A. G. NORMAN, Chemical Corps, is serving as consultant to the Soils Divisions, Bureau of Plant Industry, Soils, and Agricultural Engineering. Doctor Norman spends one day a month in Beltsville, Md., and is assisting primarily on problems relating to soil microbiology and organic matter.

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THE NATIONAL JOINT COMMITTEE ON FERTILIZER APPLICATION will meet with the American Society of Agricultural Engineers in Chicago, Ill., at the Hotel Stevens on December 15th.

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THE FIFTH INTERNATIONAL GRASSLAND CONGRESS will be held in Holland in the summer of 1949, according to P. V. Cardon, Special Assistant to the Chief of the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, who was Chairman of the United States Delegation to the Fourth Congress held in Great Britain in 1937. With the approval of Secretary of Agriculture Anderson, Dr. W. V. Lambert, Research Administrator for the Department, has asked Mr. Cardon to continue to serve in a liaison capacity with officials of the Fifth Grassland Congress, and to assist in preliminary arrangements for United States participation in the Congress. O. S. Aamodt, Head, Division of Forage Crops and Diseases in the same Bureau, has been designated as alternate to Mr. Cardon.

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Embryonic Reaction to Sodium Biselenite as a Test of Seed Vitality[1]

L. P. V. JOHNSON[2]

IN 1936, Eidmann (2)[3] described a biochemical method of seed testing based on the direct relation between intensity of embryonic reaction to sodium biselenite solution and enzymatic activity within the seed. This enzymatic activity is presumed to be, in turn, directly related to seed vitality. Later a number of other German workers reported (1, 4, 7) favorably on the use of embryonic color reaction to selenium and tellurium salt solutions as a measure of seed vitality, and during the war Lakon reported in a then unobtainable journal (5, 6) the development of a similar method involving tetrazolium salts.

Eidmann's original method, adapted from Godfrey's (3) review, may be outlined as follows:

1. Presoak seeds for 24 hours in water at room temperature.
2. Soak in 2.0% sodium biselenite ($NaHSeO_3$) until color reaction ceases (usually about 24 hours).
3. Excise embryos and classify as follows:
   - I. Entire surface of embryo dyed a rich red.
   - II. Intensively dyed only in parts of the surface, but no part of the surface entirely uncolored.
   - III. Weakly dyed throughout, or with less than two-thirds of the surface uncolored.
   - IV. Not dyed at all, or dyed weakly over not more than one-third of the surface area.

The total number of seeds in classes I and II indicates "plant potentiality" (seedling emergence). Adding the seeds of class III to this sum indicates the germinative capacity. Class IV represents non-germinable or dead seed.

The present work was undertaken to contribute in a preliminary way toward rectification of the apparent failure to make use of these methods on this continent. While the present paper was still in the

[1]Contribution from the Department of Agronomy, College of Agriculture, University of Florida, Gainesville, Fla. Received for publication June 2, 1947.

[2]Formerly Associate Professor of Agronomy, University of Florida; now Assistant Professor of Farm Crops and Assistant Geneticist, Department of Agronomy, State College of Washington, Pullman, Wash.

[3]Figures in parenthesis refer to "Literature Cited", p. 947.

course of preparation, a group of workers (8) at Iowa State College published a report on the use of the tetrazolium salt procedure as a measure of seed germinability. That work will undoubtedly stimulate interest in the tetrazolium method, and it is hoped that the present paper will perform a similar, although more belated service, for the biselenite method.

METHODS

Germination tests of small-seeded species were made on blotters in a glass-sided germinator, while large-seeded species were tested on cotton pads in covered enamelware trays. All tests were made at room temperatures (75° to 80° F). Seedling observations were made at the time of the germination counts (7 to 10 days).

Biselenite reaction tests were run simultaneously with the germination tests. Eidmann's method as outlined above was followed as the basic procedure. Variations of this procedure involved mainly the presoaking step, as follows: (a) Omitting the step entirely; and (b) presoaking the seeds for 16 hours, draining and aerating under moist conditions for 8 hours.

Classification of embryos into reaction classes was essentially according to Eidmann's definitions, the only departure being that class IV was, except for cases of very slight coloration, considered to be a nonreaction class.

All tests were on the basis of two replicates of 50 seeds each. Hard seeds (with impermeable seed coats) were classified as nongerminable or as class IV. For the most part, germination counts were made by a student assistant and the biselenite reaction determinations by the author.

In analyzing the data, a statistic, "average difference", was used to reduce replicated data. This was calculated by summating the differences (minus quantities taken as being positive) and dividing by the number of differences. The formula may be expressed as $\frac{\Sigma\,|x-y|}{N}$. Being of a survey nature, the work was not designed for the more refined forms of statistical analysis.

RESULTS

Preliminary biselenite reaction tests indicated that, while the presoaking step could be eliminated completely in testing some kinds of seeds, it was generally necessary and always advantageous. The introduction of an aeration phase in the presoaking step was a distinct advantage in most species. The data from blue lupine seeds, presented in Table 1, will serve to indicate the results generally obtained. (Presoaking was followed by soaking seeds for 24 hours in 2.0% sodium biselenite).

TABLE 1.—*Effect of variations in the presoaking procedure on sodium biselenite reaction in blue lupine seeds, average percentages from two replicates of 50 seeds each.*

Presoaking treatment	Sodium biselenite reaction classes			
	I	II	III	IV
No presoaking	7	10	43	40
Presoaking 24 hours	24	41	22	13
Presoaking 16 hours, aerating 8 hours	43	34	15	8
Nongerminable seeds	—	—	—	7
Weak seedlings	—	—	16	—

These results indicate that presoaking and aeration are essential for blue lupine seeds, presumably because these conditions are necessary for full realization of potential enzymatic activity which must be obtained if the biselenite test is to be a reliable measure of seed vitality.

The main results are summarized in Table 2.

Comparisons between data on nongerminable seeds and nonreacting (class IV) seeds show in most cases strikingly good correspondence within species. The instances where this correspondence is not good may probably be accounted for on the basis of sampling and experimental errors; but it should be remembered that the method was largely standarized and that in certain cases it may have failed to satisfy species peculiarities.

Comparison of germination and class IV data, considered over all species (A-B column), shows an average difference (3.1) no greater than that between replicates of the germination tests (3.8) or of the biselenite tests (3.1). This is considered to support the fundamental assumption of the method, *viz.*, that germination and biselenite tests both represent measures of the same thing, enzymatic activity.

It should be mentioned that data on nongerminable and nonreacting seeds are based on distinct and unmistakable negative responses. Germination tests are probably more influenced by environmental conditions than are biselenite tests. This may account for the greater average difference between replicates in the germination results.

The data on weak seedlings and weakly reacting seeds show good correspondence within species. In general, the relatively poor correspondence observed in certain species may be considered as probably due to sampling and experimental errors. In some of these cases, however, it may be that the method was not properly adjusted to peculiarities of the species in question.

Comparison of data on weak seedlings and class III seeds, considered over all species (column C-D), shows an average difference (2.9) not significantly greater than that between replicates of the seedling counts (3.9) or of the biselenite tests (2.8). This is considered to support an extended fundamental assumption, *viz.*, that the direct relation between a basic level of enzymatic activity and a capacity to germinate extends to a similar relation between higher levels of enzymatic activity and vitality of the young seedling. It was not within the scope of the present work to attempt to show the relation between the higher classes of biselenite reaction and correspondingly stronger seedlings.

The seedling results are probably more influenced by environmental conditions than are the biselenite tests, a point supported by the greater average difference between replicates of seedling counts. It should be noted that both weak seedlings and class III seeds were classified more or less arbitrarily within a range of more or less continuous variation, a fact which would be expected to contribute to increased experimental error. Attention is drawn to the fact that, while the differences between seedling and class III data may appear

TABLE 2.—*Comparison of percentage nongerminable seeds with percentage nonreacting embryos (class IV) and of percentage weak seedlings with percentage weakly reacting embryos (class III), based on data from two replicates of 50 seeds each.*

Material	Average %: Non-germinable seeds, A	Average %: Class IV seeds B	A–B	Average %: Weak seedlings C	Average %: Class III seeds D	C–D	Remarks
Alfalfa, Argentina	27	24	3	15	14	1	Fair reaction without presoaking
Barley, bearded	13	17	−4	16	19	−3	Weak reaction
Beet	33	36	−3	—	—	—	Observations complicated by multiple embryos
Carrot, Danver's	44	40	4	24	22	2	48 hours in biselenite solution
Clover, white sweet	60	67	−7	12	12	0	Reaction observed without dissection
Corn, Florida Yellow Dent	24	22	−2	21	22	−1	Reaction mainly at base of embryo
Cotton, upland	100	100	0	—	—	—	Old seed
Crotalaria spectabilis	40	44	−4	8	13	−5	Seedlings weak
Flax	8	4	4	7	5	2	Treated seeds very slippery
Kohlrabi, White Vienna	17	17	0	13	16	−3	Fair reaction without presoaking
Lespedeza, Korean	61	55	6	11	9	2	48 hours in biselenite solution
Lupine, blue	7	8	−1	16	14	2	Cotyledons react to biselenite
Millet, cattail	50	47	3	15	16	−1	48 hours in biselenite solution
Millet, German	63	54	9	7	14	−7	48 hours in biselenite solution
Oats, Fulghum	5	8	−3	14	10	4	48 hours in biselenite solution
Pea, Austrian Winter	1	3	−2	3	3	0	Cotyledons react to biselenite
Peanut, Dixie Runner	8	4	4	11	17	−6	Cotyledons react to biselenite
Radish	2	4	−2	8	10	−2	Fair reaction without presoaking
Rape, Dwarf Essex	1	1	0	4	2	2	Fair reaction without presoaking
Rye, Abruzzi	15	17	2	13	16	−3	Weak reaction
Soybean, Mammoth Yellow	3	4	−1	17	14	3	Cotyledons react to biselenite
Sudan grass	50	53	−3	7	3	4	Seed coat scarified
Turnip	14	11	3	12	15	−3	Fair reaction without presoaking
Vetch, hairy	23	20	3	32	33	−1	Cotyledons react to biselenite
Wheat, Red May	11	13	−2	10	8	2	Weak reaction
Wheat, Wood's Carala	5	6	−1	17	29	−12	Weak reaction
Av. difference between replicates x and y,	3.8	3.1	3.1	3.9	2.8	2.9	For purposes of analysis A–B and C–D are each assumed to be a difference between replicates

to be less than the corresponding differences in the nongermination nonreaction data, they tend to be based on smaller numbers (compare columns C and D with A and B, Table 2) and hence would actually be considerably greater on a percentage basis.

CONCLUSIONS

1. The sodium biselenite method of seed testing as stated by Eidmann, with the presoaking step modified to involve 16 hours presoaking and 8 hours aeration, proved generally satisfactory on seeds of a wide range of agricultural plants.

2. As a prerequisite to the first use of the method on a particular species, the relation between biselenite reaction on the one hand and seed germinability and seedling vitality on the other should be studied, and any necessary adjustments made in procedure or definition of reaction classes.

3. The biselenite test, suitably adjusted, may be used as an alternative for the standard seed germination test. It would have the advantage of being quicker, the saving in time varying from 4 to 12 days in readily germinable seeds to perhaps several months in seeds which require a period of after-ripening, assuming that the biselenite test could be made early in the after-ripening period. When perfected, the biselenite test might prove more accurate for certain purposes than the germination test.

4. The method, suitably adjusted, has possibilities for use in evaluating the potential seedling vitality of germinable seeds. It is possible, for example, to grade a lot of seed into a number of seed (or seedling) vitality classes. This would have an application in investigational work, for example, in evaluating the relative effects on seed vitality produced by a series of different storage conditions.

LITERATURE CITED

1. EGGEBRECHT, H., and BETHMANN, W. Das Selenfarbeverfahren im Vergleich zu der üblichen Keimprüfung insbesondere bei Wintergerste mit Keimruhe. Angew. Bot., 21:448–455. 1939.
2. EIDMANN, F. E. Saatgutprüfung auf biochemischen Wege. Ztschr. für Forst- und Jagdwesen, 68:422–443. 1936.
3. GODFREY, JOHN F. Review: biochemical method of seed testing. Jour. Forestry, 35:796–797. 1937.
4. LAKON, GEORG. Das Schwinden der Keimfähigkeit der Samen, insbesondere der Getreidefruchte. Ber. deutsch. bot. Ges., 57:191–203. 1939.
5. ————. Topographischer Nachweis der Keimfähigkeit der Getreidefruchte durch Tetrazoliumsalze. Ber. deutsch. bot. Ges., 60:299–305. 1942.
6. ————. Topographischer Nachweis der Keimfähigkeit der Mais durch Tetrazoliumsalze. Ber. deutsch. bot. Ges., 60:434–444. 1942.
7. MOHS, K., and TORNOW, E. Germinating energy (of grains) and selenium reduction. Ztschr. Ges. Getreidew., 27:17–22. (Abstract in Jour. Soc. Chem. Ind., 59:483B. 1940.)
8. PORTER, R. H., DURRELL, MARY, and ROMM, H. J. The use of 2,3,5-triphenyltetrazoliumchloride as a measure of seed germinability. Plant Physiol., 22: 149–159. 1947.

Runoff from Pastures in Relation to Grazing Intensity and Soil Compaction[1]

R. B. ALDERFER AND R. R. ROBINSON[2]

ONE of the chief difficulties encountered in the management of pastures is low production during hot, dry periods, particularly in July and August. This is especially true of the more intensively grazed pastures on the steeper and drier slopes. Results of studies with nitrogen fertilization, clipping treatments, and irrigation on a Kentucky bluegrass-white clover sod (14)[3] have shown that mid-summer productivity is closely associated with an adequate supply of available soil moisture. One of the conditions which affect the supply of soil moisture under actual pasture conditions is the amount of incident rainfall absorbed through the soil surface during the spring and summer months. Obviously, that portion of the rainfall which is lost as runoff is largely a loss of potentially available soil moisture.

It is now generally recognized that rainfall intensity is very important in determining the amount of runoff and erosion. In Pennsylvania, as well as in many other states, the most intense or heaviest rainstorms occur during the summer months. These storms very frequently occur during prolonged periods of high temperature, when soils are driest, and the need for moisture to maintain adequate plant growth is at a maximum. The precipitation records of the Soil Conservation Experiment Station, State College, Pa., reveal that for the 11 year period, 1935–45, inclusive, the percentages of the average total monthly rainfall which fell at rates of 1 inch or more per hour for a period of at least 15 minutes were as follows: January to April, 0%; May, 47%; June, 49%; July, 54%; August, 45%; September, 31%; October to December, 0%.

Runoff from pastures, except during periods of rapid snow melting on a frozen soil surface, is generally considered to be of little practical significance. The results of pasture runoff experiments in Ohio (5), New York (12), New Jersey (11), and Vermont (13) would tend to substantiate this view point. However, the results of investigations in Illinois (18), Missouri (16), Pennsylvania (2), and Virginia (7) show quite appreciable runoff losses from intensively grazed pastures during the summer. Soil losses from pastures, unless actively eroding gullies are present, are generally very small.

Most pasture management studies, in which runoff losses were measured, have dealt with means of influencing the amount of vegetative cover or forage through fertilization and controlled grazing.

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[3]Figures in parenthesis refer to "Literature Cited", p. 957.

Although the effect of soil compaction by cattle trampling has often been mentioned in accounting for the decreased productivity of continously, intensively grazed pastures, little direct evidence has ever been offered to support this contention. Auten (3, 4) and Chandler (6) studied the effects of grazing in forests and woodlands and showed that under grazed conditions the surface soil was more compact and had lower water-absorbing capacity than the ungrazed forest soils.

The structure of pasture soils has not as yet received much direct attention from investigators. That the structure of grazed and ungrazed grassland soils is different is very evident upon examination. The dense, compacted surface condition of many pasture soils is quite different from the porous, granular condition of undisturbed meadow or grassland soils. The greatest difference between the structure of grazed and ungrazed soils occurs at, or near, the surface. The compacting effect of cattle trampling appears to be most pronounced in the first inch of surface soil. From the standpoint of infiltration and runoff, it is this layer in the profile of well-drained soils which is most important in determining their absorptive capacity for rainfall (8). Of all the physical characteristics which regulate the moisture relationships in soils, noncapillary porosity is generally considered to be of the greatest direct importance in determining infiltration capacity and permeability (9).

The purpose of this investigation was to determine the amount of water lost as runoff during the summer from variously treated pastures on different soil types, and by analysis of the physical properties of these soils to attempt to determine the reason for this water loss, if and when it occurred.

EXPERIMENTAL PROCEDURE AND METHODS

Water was applied with a type F rainfall simulator at a rate of 1.4 inches per hour for a period of 60 minutes to plots 6 by 12 feet. Runoff was measured, and infiltration rates were calculated as the difference between the amount of water applied and that lost as runoff. Since it was impossible to make the initial runoff measurement on all sites at comparable soil moisture contents, a so-called "wet-run" was made 24 hours after the initial run. Additional wet-runs were made following clipping and removal of any mulch of dead plant material. These trials were conducted during a summer of unusually high rainfall, however, and in most cases the moisture content of the soil was rather high at the time the initial run was started. Thus, there are insufficient data for satisfactory comparisons of runoff from initially dry soil as compared with that from soil at field capacity. In the few comparisons that were obtained on heavily grazed pastures, runoff was as great in the initial run as in the corresponding wet-run. The data reported are for the wet-runs.

The mechanical analysis of the 0 to 6-inch soil layer from each site was determined by the modified pipette procedure of Alderfer and Merkle (1).

The volume weights of the 0 to 1-, 1- to 3-, and 3- to 6-inch soil layers were obtained using a sharpened steel volume weight sampling cylinder, 3.3 inches in diameter. Volume weight is expressed on the oven-dry (105° C) weight basis. From three to six separate samples were taken from each runoff site. Agreement between the volume weights of the replicate subsamples was generally very close, indicating that the degree of compaction due to cattle trampling was usually quite uniform. Volume weight samples were taken 24 hours following the wet-run so that the soil moisture content very closely approximated field capacity. Assuming that the soil at field moisture capacity had attained capillary saturation, the capillary porosity was, therefore, equivalent to the volume of water occupying the capillary pores. Assuming the density of this capillary water to be that of free water, the

capillary porosity in percentage by volume was calculated from the amount of water contained in the soil at field capacity. Total porosity was calculated on the basis of volume weight of the respective soil layer. Noncapillary porosity was calculated as the difference between total and capillary porosity.

The soil organic matter content of each layer was determined by the chromic acid titration procedure of Schollenberger (15), as modified by Tiurin (17).

The pH values were determined potentiometrically on a 2 to 1 soil-water suspension, using a quinhydrone electrode.

DESCRIPTION OF EXPERIMENTAL SITES

The trials were conducted on Hagerstown clay loams and on Morrison sandy loams on the College farms. Hagerstown soil, derived from limestone, is an excellent agricultural soil when not too severely eroded. The Morrison soil is derived from sandstone interbedded with limestone. It is considered a poor agricultural soil but shows good response to the use of lime and fertilizer.

Ten different grassland conditions were represented in this study, each of which were designated with a site number. A description of the various pasture sites is presented in Table 1. For purposes of comparison, two ungrazed sods and an abandoned pasture area were included. In 6 of the 10 sites investigated, two locations were selected for study within each site area and were designated as replicate a and b. To give some quantitative characterization to the general terms heavy, moderate, and light in designating the intensity of grazing, estimates were made of the percentage of total ground surface which was covered with some form of vegetation whether living or dead. The botanical composition of the living vegetation was estimated. The amount of herbage above 1 inch in height was measured by clipping, and the surface mulch consisting of dead vegetation was removed by hand picking. All of the pasture sites studied were at one time used for the production of tilled crops. Each of the pasture sites except no. 6 had been grazed by dairy cattle for a period of at least 10 years. Site 6 had been plowed and seeded to orchard grass and Ladino clover in 1943.

The results of volume weight, porosity, and organic matter determinations are given in Table 2. The amount of compaction to which the various pasture soils had been subjected is reflected in the volume weight of the 0 to 1-inch soil layer. Compaction also decreased noncapillary porosity and total pore space. This is evident from the high correlation coefficient (–0.81) between volume weight and noncapillary porosity in the 0 to 1-inch soil layer. The compacting effect of cattle trampling seemed to be confined largely to the 0 to 1-inch surface layer, as shown by the difference in volume weight and noncapillary porosity of the 0 to 1-inch and the 1- to 3-inch and 3- to 6-inch layers. The soil on sites 2 and 3 was artificially compacted by walking heavily on the plot when the soil was at a moisture content approaching field capacity. The volume weight of the 0 to 1-inch layer was very much increased by this treatment. In the 1- to 3- and 3- to 6-inch layers the granular structure normally associated with grassland soils remained relatively undisturbed. Noncapillary porosity within these layers was usually very great.

It is not unusual that the organic matter content is greatest in the 0 to 1-inch layer. In addition to the accumulation of decomposed leaves and stems, it is in this 0 to 1-inch layer that the majority of Kentucky bluegrass and white clover roots are concentrated in pasture soils (10).

Mechanical analysis of the 0 to 6-inch surface layer from the sites on Hagerstown soil showed, in general, ranges of 18 to 32% clay, 35 to 45% silt, 20 to 25% fine sand, 3 to 10% coarse sand, and 5 to 10% gravel. The clay content was not correlated with volume weight. Hagerstown subsoil contains 40 to 45% clay. The Morrison soil was found to contain 13% clay, 27% silt, 21% fine sand, 34% coarse sand, and 5% gravel.

The pH determination showed that on all except No. 9 the soil had been adequately limed.

EXPERIMENTAL RESULTS

Runoff losses during 1 hour of simulated rainfall applied at the rate of 1.4 inches per hour ranged from none on sites 3, 7b, 8a, and 8b,

none of which had been grazed, to 80% of the water applied on site 1b, a poor sod that was heavily grazed (Table 3). With 80% runoff, the effective rainfall was equivalent to only 0.28 inch.

Except on sites where little runoff occurred, the rate of water loss increased rapidly to a maximum and then remained relatively constant. This is illustrated in Fig. 1 for sites showing wide variations in rate of runoff. On site 1b, as shown in Table 3, the maximum rate of runoff amounted to 91% of the water applied.

TABLE 1.—*Description of the sites investigated.**

Site No.	Percentage surface cover	Botanical composition of surface cover†	Grazing intensity	Percentage slope	Dry weight of clipped herbage, lbs. per acre	Dry weight of mulch, lbs. per acre
		Hagerstown Soil				
1	55	10% white clover 25% Ky. bluegrass 20% weeds	Very heavy	30	None	None
2	90	20% white clover 10% black medic 30% Ky. bluegrass 30% weeds	Moderate	27	518	None
3	100	40% Ky. and Can. bluegrass 60% ground mulch	None Retired 5 years	25	1,070	3,090
4	85	30% white clover 35% Ky. bluegrass 20% weeds	Heavy	21	None	None
5	100	40% white clover 55% Ky. bluegrass 5% weeds	Light	20	710	Thin layer of decomposed manure not removed
6	85	20% Ladino clover 65% orchard grass	Moderate	23	380	None
7	100	45% red clover 55% timothy	None	15	2,900	1,950
8	100	100% orchard grass	None	12	2,530	3,000
		Morrison Soil				
9	50	20% redtop 5% bluegrass 25% weeds	Moderate	17	100	None
10	85	28% white clover 50% Ky. bluegrass 7% weeds	Heavy	17	None	None

*All sites except 2, 3, 9, and 10 are in duplicate.
†Sites 1, 2, 3, and 9 had not received fertilizer; all others had been fertilized.

TABLE 2.—*Soil properties of the sites investigated.*

Site No.	Site description and treatment	Depth of sample, in.	Volume weight	Porosity, %			Organic matter, %
				Non-capillary	Capillary	Total	
	Hagerstown Soil						
1	Bluegrass-clover, heavily grazed, 55% cover	0–1 1–3 3–6	1.80 1.50 1.26	6.1 24.4 33.7	26.0 19.0 18.8	32.1 43.4 52.5	2.89 1.83 0.62
2	Bluegrass-clover, moderately grazed, 90% cover	0–1 1–3 3–6	1.47 1.19 1.22	19.2 37.7 37.6	25.4 17.4 16.4	44.6 55.1 54.0	3.76 2.53 2.14
2	Same plot as above, trampled by foot	0–1	1.64	8.6	29.6	38.2	3.76
3	Bluegrass, ungrazed for 5 years, 100% cover	0–1 1–3 3–6	1.09 1.36 1.34	33.1 25.9 28.3	25.8 23.8 21.1	58.9 49.7 49.4	3.31 2.34 1.83
3	Same plot as above, trampled by foot	0–1	1.41	16.6	30.2	46.8	3.31
4	Bluegrass-clover, heavily grazed, 85% cover	0–1 1–3 3–6	1.61 1.19 1.28	9.2 33.5 30.5	30.0 21.6 21.2	39.2 55.1 51.7	4.63 2.42 2.18
5	Bluegrass-clover, lightly grazed, 100% cover	0–1 1–3 3–6	1.27 1.29 1.53	18.2 26.1 18.5	33.9 25.2 23.8	52.1 51.3 42.3	4.88 2.13 1.69
6	Orchard grass-Ladino clover, moderately grazed, 85% cover	0–1 1–3 3–6	1.55 1.41 1.48	10.9 24.2 22.3	30.6 22.6 21.9	41.5 46.8 44.2	2.57 1.78 1.40
7	Red clover-timothy, cut for hay; corn, oats, wheat, hay rotation; 100% cover	0–1 1–3 3–6	1.46 1.41 1.41	24.2 27.2 28.1	20.7 19.6 18.7	44.9 46.8 46.8	2.24 1.89 1.61
8	Orchard grass sod, ungrazed, 100% cover	0–1 1–3 3–6	1.44 1.33 1.36	17.7 24.4 22.6	28.0 25.4 26.1	45.7 49.8 48.7	3.15 2.79 2.67
	Morrison Soil						
9	Redtop-weeds, moderately grazed, 50% cover	0–1 1–3 3–6	1.96 1.49 1.54	5.1 25.3 24.0	20.9 18.5 17.9	26.0 43.8 41.9	2.06 1.24 0.78
10	Bluegrass-clover, heavily grazed, 85% cover	0–1 1–3 3–6	1.79 1.54 1.53	9.6 23.6 24.9	22.9 18.3 17.4	32.5 41.9 42.3	2.95 1.34 0.96

Runoff was greatest on the heavily grazed plots. The average water losses ranged from 33 to 80% on the five heavily grazed plots, 1 to

50% on the six moderately to lightly grazed plots, and 0 to 2% on the five ungrazed plots. In general, clipping the lightly grazed or ungrazed areas greatly increased runoff (sites 2, 5b, 7a, 7b, and 8a). In a few cases little or no water loss occurred even after clipping (sites 3, 5a and 8b). On these three sites, however, the soil was especially well protected. Site 3 had not been clipped or grazed for five years and had accumulated an excellent mulch of dead grass. Even after the mulch was removed, water loss averaged only 6% of the water applied, indicating a high degree of granule stability. Site 5a was covered with about ¼ inch of partially decomposed manure. (Site 5b was only partially covered with a thinner layer of manure.) Site 8b was covered with a heavy mulch of dead grass. In all cases, clipping the herbage and removing any mulch of plant material significantly increased runoff losses.

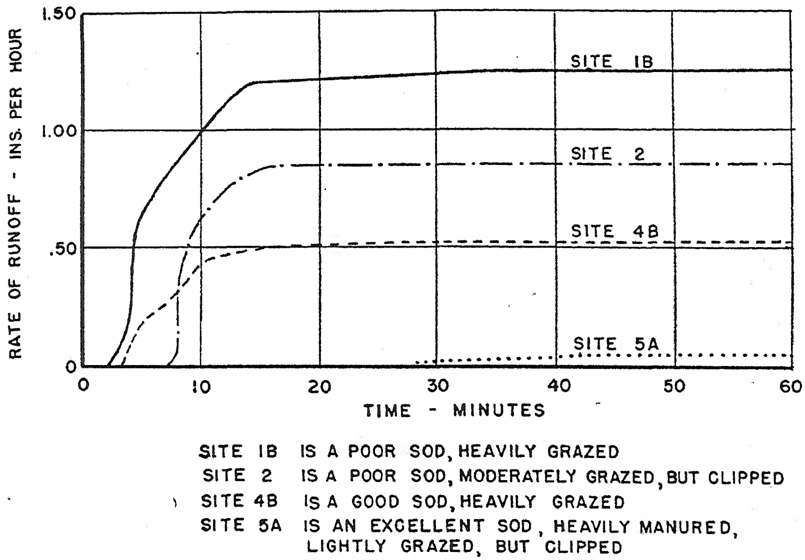

FIG. 1.—Runoff hydrograph, showing the rate of water loss from differently treated pastures on Hagerstown soil during a 1.4-inch per hour rain.

Heavy grazing not only reduced vegetative cover but decreased noncapillary porosity and increased the volume weight of the 0 to 1-inch layer of soil. In the 0 to 1-inch layer, noncapillary porosity ranged from 3 to 10% for the heavily grazed plots as compared with 15 to 33% for ungrazed and lightly grazed plots. Similarly, volume weights ranged from 1.54 to 1.91 on the heavily grazed sites and from 1.09 to 1.51 on ungrazed and lightly grazed sites. In the 1- to 3- and the 3- to 6-inch layers, on the other hand, volume weights apparently were not significantly affected by intensity of grazing.

The relationship between the volume weight of the 0 to 1-inch layer and the average percentage runoff for the sites on Hagerstown soil is shown in Fig. 2. To minimize the effect of vegetation or mulch

TABLE 3.—*Infiltration and runoff data from various pasture and grassland soils.*

Site No.	Site description and treatment	Runoff, %		Infiltration rate, in. per hour		Volume weight		Noncapillary porosity, %	
		Av.	Max.	Av.	Min.	0–1 in.	1–6 in.	0–1 in.	1–6 in.
	Hagerstown Soil								
1a	Bluegrass-clover, heavily grazed, 60% cover	71	75	0.41	0.35	1.69	1.41	9.2	28.1
1b	Bluegrass-clover, heavily grazed, 50% cover	80	91	0.28	0.13	1.91	1.31	3.0	31.2
2	Bluegrass-clover, moderately grazed, 90% cover	19	21	1.13	1.11	1.47	1.21	19.2	37.0
2	Same plot as above, but clipped to 1 inch	52	64	0.67	0.50	—	—	—	—
2	Same plot as above, trampled by foot after clipping	67	80	0.46	0.28	1.64	1.21	8.6	37.0
3	Bluegrass sod ungrazed for 5 years, 100% cover	0	0	1.40	1.40	1.09	1.35	33.1	25.3
3	Same plot as above, but clipped to 1 inch	0	0	1.40	1.40	—	—	—	—
3	Same plot as above, mulch removed after clipping	6	11	1.32	1.25	—	—	—	—
3	Same plot as above, trampled by foot after mulch removal	36	55	0.90	0.63	1.41	1.35	16.6	25.3
4a	Bluegrass-clover, heavily grazed, 85% cover	39	45	0.77	0.67	1.67	1.25	8.6	33.0
4b	Bluegrass-clover, heavily grazed, 80% cover	33	38	0.85	0.77	1.54	1.26	10.2	30.4
5a	Bluegrass-clover, lightly grazed, 100% cover	1	4	1.39	1.34	1.18	1.42	22.1	21.7
5b	Bluegrass-clover, lightly grazed, 100% cover	5	9	1.33	1.27	1.36	1.45	15.3	21.4
5a	Same plot as 5a above, but clipped to 1 inch	1	4	1.39	1.34	—	—	—	—
5b	Same plot as 5b above, but clipped to 1 inch	21	30	1.11	0.98	—	—	—	—
6a	Orchard grass-Ladino clover, moderately grazed, 75% cover	26	39	1.04	0.85	1.60	1.42	7.7	24.5

6b	Orchard grass-Ladino clover, moderately grazed, 90% cover	6	13	1.32	1.22	1.49	1.49	14.5	21.3
6a	Same plot as 6a above, but clipped to 1 inch	49	59	0.71	0.57	—	—	—	—
6b	Same plot as 6b above, but clipped to 1 inch	42	52	0.81	0.67	—	—	—	—
7a	Red clover-timothy meadow, 100% cover	2	7	1.37	1.30	1.45	1.37	24.2	29.2
7b	Red clover-timothy meadow, 100% cover	0	0	1.40	1.40	1.47	1.45	24.5	27.1
7a	Same plot as 7a above, but clipped to 2 inches	23	34	1.08	0.92	—	—	—	—
7b	Same plot as 7b above, but clipped to 2 inches	26	38	1.04	0.87	—	—	—	—
7a	Same plot as 7a above, but mulch removed after clipping	42	63	0.81	0.52	—	—	—	—
7b	Same plot as 7b above, but mulch removed after clipping	47	71	0.74	0.41	—	—	—	—
8a	Orchard grass, ungrazed, 100% cover	0	0	1.40	1.40	1.36	1.41	19.8	20.0
8b	Orchard grass, ungrazed, 100% cover	0	0	1.40	1.40	1.51	1.29	16.0	23.8
8a	Same plot as 8a above, but clipped to 1 inch	28	38	1.00	0.87	—	—	—	—
8b	Same plot as 8b above, but clipped to 1 inch	1	3	1.39	1.36	—	—	—	—
8a	Same plot as 8a above, mulch removed after clipping	47	64	0.74	0.50	—	—	—	—
8b	Same plot as 8b above, mulch removed after clipping	6	11	1.32	1.25	—	—	—	—
	Morrison Soil								
9	Redtop-weeds, moderately grazed, 50% cover	50	61	0.70	0.55	1.96	1.52	5.2	24.4
10	Bluegrass-clover, heavily grazed, 85% cover...........	41	48	0.83	0.73	1.79	1.53	9.5	24.2

cover, the runoff values used were those obtained after clipping and after removal of any mulch of dead vegetation. Included in Fig. 2 are the data obtained on sites 2 and 3, following tramping while the soil was wet. The correlation coefficient (0.80) for this relationship is highly significant (odds exceed 99 to 1). Site 8b is furthest out of line in this relationship. For some reason this soil, even after the removal of the mulch of dead grass, was highly resistant to dispersion and therefore runoff was low. Although sites 8a and 8b appeared to be very similar, the soil on 8a lacked this high degree of granule stability and runoff was much greater.

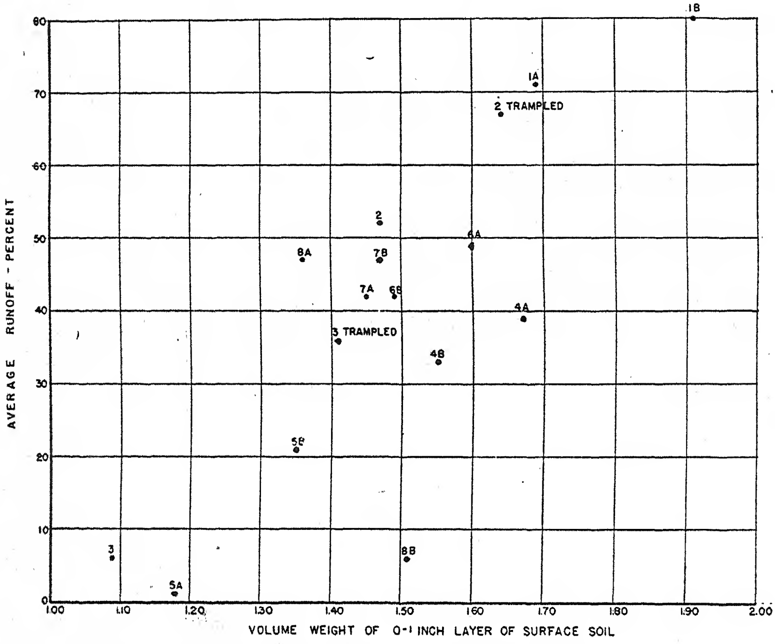

FIG. 2.—Relation between runoff and compaction of the 0 to 1-inch layer of surface soil. The numbers in the chart refer to sites.

Runoff was also highly correlated with noncapillary porosity. The correlation coefficient for this relationship is 0.76.

SUMMARY AND CONCLUSIONS

Runoff losses during the summer from various sites in pastures and grasslands on Hagerstown and Morrison soils were determined by means of a type F rainfall simulator. Water losses were supplemented by measurements of vegetative cover, percentage slope, volume weight, capillary and noncapillary porosity, organic matter content, pH, and the mechanical analysis of the soil.

Runoff losses ranged from none to 80% during a 1-hour period in which 1.4 inches of water were applied. In general, water losses were

high from heavily grazed pastures, whereas ungrazed areas lost little if any water due to runoff.

The high rate of runoff from the heavily grazed sites was associated with lack of soil cover together with high volume weights and low values for noncapillary and total porosity in the 0 to 1-inch surface soil layer. Compaction was confined to the 0 to 1-inch layer even though this layer contained the greatest amount of organic matter. This is indicated by low volume weights and high noncapillary porosity in the 1- to 3- and 3- to 6-inch soil layers.

Since storms of high rainfall intensity are common during the summer months, it is suggested that water loss due to runoff may be an additional factor contributing to the low yields of closely grazed pastures during midsummer.

LITERATURE CITED

1. ALDERFER, R. B., and MERKLE, F. G. The measurement of structural stability and permeability and the influence of soil treatments upon these properties. Soil Sci., 51:201–212. 1941.
2. ————, and BRAMBLE, W. C. The effect of plant succession on infiltration of rainfall into Gilpin soil in central Pennsylvania. The Pa. State Forest School Res. Paper No. 5. 1942.
3. AUTEN, JOHN T. Porosity and water absorption of forest soils. Jour. Agr. Res., 46:997–1014. 1933.
4. ————. The effect of forest burning and pasturing in the Ozarks on the water absorption of forest soils. U. S. Forest Service, Central States Forest Exp. Sta. Note 16. 1934.
5. BORST, HAROLD L., MCCALL, A. G., and BELL, F. G. Investigations in erosion control and the reclamation of eroded land at the Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, 1934–42. U.S.D.A. Tech. Bul. 888. 1945.
6. CHANDLER, ROBERT F., JR. The influence of grazing upon certain soil and climatic conditions in farm woodlands. Jour. Amer. Soc. Agron., 32:216–230. 1940.
7. DICKERSON, W. H., JR., and ROGERS, H. T. Surface runoff and erosion from permanent pastures in southwest Virginia as influenced by applications of triple superphosphate. Va. Agr. Exp. Sta. Tech. Bul. 77. 1941.
8. DULEY, F. L., and KELLY, L. L. Effect of soil type, slope, and surface conditions on intake of water. Neb. Agr. Exp. Sta. Res. Bul. 112. 1939.
9. FREE, G. R., BROWNING, G. M., and MUSGRAVE, G. W. Relative infiltration of certain soils in comparison with their physical characteristics. U.S.D.A. Tech. Bul. 729. 1939.
10. HAYNES, J. L. Effects of pasture practices on root distribution. Jour. Amer. Soc. Agron., 35:10–18. 1943.
11. ————, and NEAL, O. R. The effect of certain pasture practices on runoff and production of protective cover. Jour. Amer. Soc. Agron., 35:205–211. 1943.
12. JOHNSTONE-WALLACE, D. B., ANDREWS, JOHN S., and LAMB, JOHN, JR. The influence of periodic close grazing and pasture fertilization upon erosion control. Jour. Amer. Soc. Agron., 34:963–974. 1942.
13. MIDGLEY, A. R., PLATH, C. V., and MAYERNIK, J. J. Erosion on Vermont permanent pastures. Vt. Agr. Exp. Sta. Bul. 483. 1942.
14. ROBINSON, R. R., and SPRAGUE, V. G. The clover populations and yields of a Kentucky bluegrass sod as affected by nitrogen fertilization, clipping treatments, and irrigation. Jour. Amer. Soc. Agron., 39:107–116. 1947.
15. SCHOLLENBERGER, C. J. Determination of soil organic matter. Soil Sci., 31: 483–486. 1931.
16. SMITH, D. D., WHITT, D. M., ZINGG, A. W., MCCALL, A. G., and BELL, F. G. Investigations in erosion control and reclamation of eroded Shelby and related soils at the Conservation Expt. Sta., Bethany, Mo., 1930–42. U. S. D. A. Tech. Bul. 883. 1945.

17. TIURIN, J. W. A new modification of the volumetric method of determining soil organic matter by means of chromic acid. Pedology, 5–6:36. 1931.
18. VAN DOREN, C. A., BURLISON, W. L., GARD, J. E., and FUELLEMAN, R. F. Effect of soil treatment and grazing management on the productivity, erosion and runoff from pasture land. Jour. Amer. Soc. Agron., 32:877–887. 1940.

Viability and Seed Treatment of Flax[1]

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HIGH germinating power of the seed is one among several important factors in obtaining a good stand of flax. The viability of Kansas-grown flaxseed, some of the causes of low germination, and the effect of treating seed on emergence and yield are discussed in this paper.

REVIEW OF LITERATURE

Landon (11)[3] stated that good flax seed should have a germination of more than 95%. He stated further that flax seed was more subject to weather damage than wheat or oats, and in some years the weather conditions at the time of ripening may be such that seed of low germination is produced. Dillman and Stoa (5) advised keeping the seed bolls off damp ground after harvest and cautioned that flax intended for seeding purposes should be recleaned before storing, thus removing shriveled and broken seeds, weed seed, and broken stems.

Dillman and Toole (6) reported that flax seed of good quality stored under favorable conditions maintained a high degree of viability for 10 years or more, but weather-damaged or low-quality seed lost its viability rapidly, beginning with the first year, and in extreme cases was worthless for planting. Seed stored with more than 11% moisture gave low germination only 6 months after harvest. The variety Linota gave somewhat higher germination than Bison in the tests.

Decker and Reitz (3) showed that viability of stored flax declined rapidly if moisture and temperature levels were high. Stored with 13% moisture, Linota flax lost its viability completely after 60 days at 86°F but showed only slight decline when stored at 40° or 70°. Lower moisture levels prolonged viability at all temperatures.

Dillman (4) found that seeds collected and cured from bolls 9 to 12 days after flowering did not germinate between blotters in a moist chamber. Those collected at later periods showed germinations of 38% after 15 days, 80% after 18 days, 90% after 24 days, and an average of 95% for samples harvested 27 to 36 days after flowering. Robinson (17) obtained similar results on bulk seed samples from whole plants instead of selected bolls of known age. Samples taken at weekly intervals, beginning with the full bloom stage, gave germinations of 4.7, 61.3, 82.6, and 89.6%, respectively, indicating the low viability of immature seeds. These samples were cured slowly in the shade while comparable samples cured in the sunlight in a greenhouse germinated 0, 7.3, 15.3, and 93.6%, respectively. Fanning the seed sometimes increased the germination 10% or more as a result of removing light weight, underdeveloped seeds.

Landon (11) explained that low yields of Bison in some of his tests were due to low germination of the seed and subsequent poor stands. Davidson and Laude (2) reported that more Bison seeds were cracked during threshing than was the case with small-seed varieties such as Linota. Bison seed frequently was lower in test weight per bushel than Linota, indicating somewhat poorer development of the seed.

Stevens (19) tested 11 samples of Bison flax seed showing four types of mechanical injury. His results from soil tests in the laboratory chamber showed that uninjured seed germinated 89%, cracked seed 73%, slightly broken 57%, more than one-half seed with plumule 38%, and less than one-half seed with plumule 13%. In field tests these grades of seed germinated 63, 30, 20, 8, and 3%, respectively.

Machacek and Brown (13) reported that flax seed was often fractured when

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[3]Figures in parenthesis refer to "Literature Cited", P. 969.

threshed during dry weather. The fractures were generally minute and invisible to the unaided eye, and large-seed varieties were more frequently cracked than small-seed ones. Treatment of fractured kernels with suitable seed disinfectants prevented their decay. In heavy soils, New Improved Ceresan applied at the rate of 1½ ounces per bushel gave the best results. Seed treatment generally improved the germination of fractured seed under experimental plot conditions, but the increase in stand did not always result in improved yield. Similar results were obtained by Schuster, Forsyth, and Harrar (18) who also showed that the large-seed varieties Bison and Rio were cracked more than Redwing and Zenith. Field stands were improved 7 to 87% by seed treatment.

Burnett and Reddy (1) got improved stands and higher yields from all varieties when the seed was treated with Ceresan before planting. In a later summary, Reddy and Burnett (16) reported the average stands of six varieties were improved 40% and the yields 16.7% during the years 1930 to 1932. Their data showed that the greatest relative improvement in yield occurred in Buda and Bison, and the least improvement in the Linota and Redwing varieties. Tests in 1932 with New Improved Ceresan showed yields of Bison were increased 13.1%, Redwing 18.0%, and Golden 76.1%.

Tervet (22) found that fungi belonging to seven genera, some of which were seed-borne, caused varying degrees of injury to seedling flax. Seed treatment helped to protect the seedlings from these fungi. Forsyth and Vogel (8) found that two important causes of yearly variation in initial stands of flax were mechanical damage to the seed, caused mainly by machine threshing, and the presence of soil-borne organisms, mainly *Fusarium oxysporum*.

Moore and Christensen (15) found three kinds of injury to flax seed of frequent occurrence, *viz.*, mechanical cracking and shattering of the seedcoat, discoloration and roughening of the seedcoat due to fungi and weathering, and exposure of the embryo due to the natural tendency of seed of certain varieties to split at the germ end. Embryo exposure was the most common, and golden-seed varieties were much more subject to it than brown-seed varieties. Seed lots from the golden-seed variety C. I. 976 from 31 localities in the United States and Canada showed from 6 to 83% exposed embryos. Lots of injured seed tended to respond to seed treatment more frequently than noninjured, and golden-seed varieties responded more frequently than brown-seed ones. Ceresan and Arasan were about equally effective in increasing the stand.

Flor (7) summarized seed treatment tests conducted for four years in Montana, North and South Dakota, and Minnesota. Beneficial response was obtained in the eastern part of the area. Moore (14), Greany (9, 10), and Machacek (12) in co-operative flax seed treatment tests conducted in northern United States and Canada from 1940 to 1946 reported that when fractured seed was treated with New Improved Ceresan, DuBay 1452–F, Arasan, and Spergon, beneficial increases in stand and yield were generally obtained; but when sound, high-quality seed was treated, beneficial increases in stand and yield were seldom obtained. Treating of seed lots with New Improved Ceresan at 1 and 1½ ounces per bushel was more effective than treating at ¼ and ½ ounce rates. New Improved Ceresan was somewhat superior to the other fungicides.

Sylvén (20) suggested that a genetic basis might be involved in viability of certain types, and that the amount of moisture in the soil influenced germination of varieties. Two brown-seed varieties, one having blue and the other white blossoms, were studied. Under favorable soil conditions and normal watering, the blue blossom type was superior in germination and seedling vigor to the white blossom type, with the F_2 hybrid being intermediate. However, with one-fourth normal watering, the white blossom type exceeded the blue. Tammes (21) crossed a white crimp-petaled variety having yellow anthers and green seeds with the common blue flax and found a deficiency of whites in segregating generations. This she attributed to the factor C^1 having a semi-lethal effect in white forms, with white less viable and forming fewer seeds per boll.

MATERIALS AND METHODS

The seed laboratory at Manhattan, Kansas, operated by the Kansas State Board of Agriculture, has received each year from farmers, seed companies, and others, numerous samples of flax seed for germination tests. The variety name was given often enough on four varieties to make possible varietal comparisons.

Authenticity was checked by seed characters and certification records. In germinating these samples, this laboratory used methods approved by the Association of Official Seed Analysts of North America consisting of a 7-day blotter test at alternating temperatures of approximately 20°C at night and 30°C during the day.

A number of other seed samples were collected from experiment station variety test plots and germinated, thus affording a comparison of varieties grown and handled under more uniform field and threshing conditions than in the case of samples submitted to the seed laboratory. Agronomic data on several varieties were obtained at the experiment field at Thayer, Kans.

Experiments on the effect of treating flax seed with different fungicides on emergence were conducted in the field at Manhattan, Kans., 1943–45, and at Thayer, Kans. 1944–45. The brown-seed varieties Linota, Bison, and Redwing, and the yellow-seed varieties Viking and B. Golden were used in these tests. The seed was obtained from growers in southeastern Kansas. The percentage of laboratory germination varied with different varieties and years. The fungicides used were New Improved Ceresan at ½ and 1 ounce, DuBay 1452–F at ½ and 1 ounce, Arasan at 2 ounces, Spergon at 3 ounces, and Phygon at 2 ounces per bushel. The treatments were planted in randomized rows with 200 seed to each 8 feet. Notes were taken on the emergence of the seedlings in the four replications, and the data analyzed statistically.

Experiments on the effect of treating flax seed on yield were conducted at Thayer, Kans., in 1945 and 1946. The varieties Linota and Bison in 1945, and, in addition, Koto in 1946, were treated with New Improved Ceresan at ½ and 1 ounce per bushel. The treatments were randomized and planted in five replications of rod rows. The flax was harvested and threshed and the yields analyzed statistically.

RESULTS

VIABILITY OF FLAX AND SOME CAUSES OF LOW GERMINATION

The average viability of flax samples submitted to the seed laboratory is shown in Table 1 for 12 crop years. The annual average germination ranged from 73% in 1944 to 91% in 1940, a spread of 18%. The three lowest years were 1943, 1944, and 1945. The large increase in the flax acreage in 1943, and hence larger demand for seed, caused growers to submit more samples from the 1942 crop than from other years. Low germination occurred in 1942 and 1943 when the demand for seed was greatest. There are two possible explanations for the low germination in these years. First, the larger demand for seed may have caused growers to submit proportionately more questionable samples to the laboratory for test than in other years; and second, growing conditions may have been less satisfactory for the production

TABLE 1.—*Germination tests on all flax seed submitted to the seed laboratory 1934 to 1945, Manhattan, Kans.*

Crop year grown	Number of samples	Av. % of germination	Crop year grown	Number of samples	Av. % of germination
1934	40	90			
1935	59	86	1941	230	80
1936	45	90	1942	531	79
1937	51	82	1943	327	76
1938	77	84	1944	141	73
1939	172	89	1945	131	75
1940	245	91	Total.....	2049	—
Weighted av.				—	81.2

of high quality seed. If the former were true, it should not have affected the 1943 crop more than the 1942 crop, since the acreage sown to flax declined in Kansas in 1944 when the 1943 crop seed would have been used. The second factor, that of seasonal variation, was studied and it appeared to be related to seed viability in certain years.

The most pronounced influence of seasonal factors appeared to be the occurrence of heavy rains at the time the flax was maturing and during the harvest season. Usually this critical time in Kansas includes the period July 10 to 31, but may begin earlier or extend later if harvest is delayed. Such weather damage may occur in the field or in the bin if storage conditions are unsatisfactory or the seed too moist when binned. Examination of U. S. Weather Bureau records for stations in the flax belt of Kansas showed that the years 1934, 1935, 1936, 1939, and 1940 were dry during July; however, the years 1937, 1942, 1944, and 1945 were wet during July, especially at the time flax should be harvested. In 1941 a dry period prevailed from July 11 to 25 but was followed by a moist period during the last six days of the month. In 1943, precipitation was below average both in July and August and temperatures were above average, but moderate rains occurred in the middle of July and again at the close of the month and during the first few days of August. Delays in harvesting the 1943 crop undoubtedly exposed the flax crop to more weather damage. The year 1944 was one of the wettest on record. August rainfall in the eastern and middle sections of Kansas was about twice normal, although most of this came after the fifteenth of the month. Rather heavy rain fell in this part of Kansas in July, especially July 7 to 12 and 24 to 31. In 1945, more than average precipitation fell in June and July, with some heavy rains the first 11 days of August in the flax area of the state. In general, the viability of the seed and the weather conditions prevailing during the ripening and harvest period were related.

Table 2 indicates the relative germinating power of four varieties submitted to the seed laboratory by farmers. It may be observed that 261 Linota samples averaged 85.1% compared with 82.4% for 65 Redwing samples, 77.7% for 124 Bison samples, and 68.8% for the 17 samples of Viking. In 1940, all varieties germinated satisfactorily with the possible exception of Viking. In 1941, Linota exceeded all varieties, while in 1942 Linota and Redwing were about equal, being superior to the other two varieties. In 1943, Linota and Redwing were highest again, followed in order by Bison and Viking. In 1944, Redwing and Linota exceeded Bison. Three-fourths of the Linota and over two-thirds of the Redwing samples germinated better than 80%, while less than two-thirds of the Bison samples were above 80. There were 17 samples of Viking, but only 1 of these germinated above 90%. From calculations involving standard errors it was found that Linota and Redwing did not differ significantly, nor was there a significant difference between Bison and Viking. However, Linota and Redwing showed marked superiority over the other two varieties, as indicated by highly significant statistical differences. These data suggest that high viability may be more difficult to

obtain in some varieties, such as Bison and Viking. If this is true, seed growers must take even greater care in harvesting, threshing, and storing seed of such varieties.

TABLE 2.—*Germination test on four varieties of flax seed submitted to the seed laboratory, 1940 to 1944, Manhattan, Kans.*

Crop year grown	Linota		Bison		Redwing		Viking	
	No.	Av. % germination	No.	Av. % germination	No.	Av. % germination	No.	Av. % germination
1940	60	92.5	16	92.8	10	94.1	2	85.5
1941	44	86.8	17	76.7	6	78.7	6	70.2
1942	72	84.0	48	76.9	16	83.4	8	64.4
1943	60	79.3	34	73.8	26	78.0	1	62.0
1944	25	80.9	9	72.3	7	83.3	0	—
Total......	261	—	124	—	65	—	17	—
Weighted average	—	85.1	—	77.7	—	82.4	—	68.8

Germination of flax seed from field experiments is shown in Table 3. All germination tests were made in January, 1944, or March, 1946, so some of the seed was several years old. In the 13 direct comparisons of Linota and Bison, these varieties averaged 86.7 and 72.6% germination, respectively. There was only one case when Bison germinated better than Linota, and in no case was Bison as good as Redwing. Redwing averaged 87.2% in all tests and was equal to or better than Linota in all but two cases. The varieties with yellow seed and white blossoms, Viking and the Golden selections C. I. 644, C. I. 976, and C. I. 977, were without exception below Linota and Redwing in germination. Poor stands were obtained many times at the Thayer Experiment field with these yellow-seed varieties, Crystal, and others, and some were discarded because of this factor. The other three selections, C. I. 890, 980, and Koto, which have brown seeds and blue flowers, perhaps occupy positions intermediate between Bison and Linota, although the number of samples was insufficient to be conclusive. Also tested, but not shown in Table 3, were three selections grown in plots at Thayer from the cross Bison×Redwing known by the names or designations Redson, Biwing, and C. I. 914. Seed from the 1942 crop gave germinations of 76%, 28%, and 20%, respectively; and seed from the 1943 crop germinated 81%, 93% and 89%, respectively. In 1942, therefore, Redson was the only one of the three with germination equal to Linota and Redwing, while in 1943 all were reasonably satisfactory but not equal to Redwing. Germination of nursery seed from the 1942 and 1943 crops of Biwing was 88 and 83% in the two years, 4% below Redwing in each case.

The purity records on samples sent to the seed laboratory from the 1942, 1943, and 1944 crops identified by variety name were chosen for study to determine the relationship between the condition of the

seed and germination. A comparison of 66 samples of Linota with 42 of Bison from the 1942 crop showed 0.5% higher purity for Linota, which did not appear to have any significance.

TABLE 3.—*Germination percentages for flax varieties grown in nursery and plot experiments, Kansas Agricultural Experiment Station.**

Station	Year grown	Percentage germination								
		Linota	Bison	Redwing	Viking	Golden C. I. 976	Golden C. I. 644	C. I. 890	C. I. 980	Koto
Thayer nursery	1939	95	86	—	79	92	—	94	94	—
Thayer nursery	1940	—	—	89	76	84	80	84	79	—
Manhattan nursery	1940	64	32	73	—	—	62	—	—	33
Thayer nursery	1941	86	61	87	73	68	75	74	75	—
Manhattan nursery (early)†	1941	87	66	88	—	70	—	—	—	—
Manhattan nursery (late)†	1941	85	65	89	—	76	—	—	73	—
Thayer nursery	1942	92	86	92	73	79‡	75	83	90	90
Thayer nursery	1943	95	77	87	74‡	81	56	87	80	81
Thayer nursery (second planting)	1943	96	79	—	—	—	—	—	—	—
Wichita plots	1943	98	95	98	—	—	—	—	—	—
Thayer plots	1942	73	70	78	—	—	—	—	—	71
Thayer plots	1943	83	89	96	—	—	—	—	—	94
Thayer nursery§	1944	79	51	73	53‡	71	41	—	53	61
Thayer nursery§	1945	94	87	96	—	—	—	90	93	91

*All samples were tested in January, 1944.
†Early and late dates of planting.
‡C.I. 977.
§Tested in March, 1946.

Records for 1943 were available for 46 samples of Linota, 17 samples of Redwing, and 25 samples of Bison. All contained broken seeds. In some cases, broken seeds constituted the only form of inert matter and were by far the most important defect in most samples. Other inert matter consisted of broken stems, leaves, and parts of bolls, with an occasional notation of soil in the sample. Germination and content of inert matter showed a slight negative correlation of -0.302 ± 0.097, but it was of such low order that it would be of little use for prediction purposes. Official procedure in the seed laboratory requires that broken pieces consisting of one-half seed or less be classified with inert matter and are not used in the germination test. Thus, much of the broken seed would not be involved in germinating a sample in the laboratory. Samples containing a large amount of such inert matter also contained cracked or chipped seeds consisting of pieces larger than one-half seed. These, as shown by Stevens (19), would have low germination in the soil but might not degrade the laboratory readings appreciably. Total inert matter in the Linota and Redwing samples averaged 3.7 and 3.2%, respectively, while Bison samples averaged 5.4%. Since the inert matter was largely broken seeds, Bison samples showed more mechanical injury than the other varieties. This difference was statistically significant.

In 1944, six samples of Redwing averaged 1.8% inert matter; eight of Bison, 2.4%; and 21 of Linota, 3.4%. Weed seeds and other crop seeds accounted for 0.1% in Redwing, 0.6% in Linota, and 1.2% in Bison on the average for the 1943 crop. This order might be significant, since later maturing flax, such as the Bison variety, would be most likely to contain weeds under Kansas farm conditions.

Agronomic characteristics of six varieties and their yield of seed in southeast Kansas are shown in Table 4. Koto gave the highest average yield of seed, while the yellow-seed variety C. I. 644 yielded least. Bison had the lowest test weight and was latest in time of blossoming. Viking was grown from 1940 to 1942. During that period it blossomed at about the same time as Redwing, was 4 inches shorter, had lower test weight, and yielded less seed by 1.5 bushels per acre than Redwing. Field stands were estimated in 1940, 1942, 1943, and 1944. Linota and Redwing averaged 86 and 87%, respectively, in contrast to the Golden varieties which averaged 76%. In three years when Viking was compared with C. I. 644, it had poorer stands one year and practically the same estimate in the other. Laboratory germination of the seed from some of these nursery tests was reported in Table 3.

TABLE 4.—*Average of agronomic data on flax varieties grown in nursery experiments, Thayer, Kans., 1940 to 1943, and seed yields 1939 to 1944.*

Variety	C. I. No.	Date		Height, ins.	Test weight, lbs.	Yield, bus. per acre		Av. stand % 1940, 1942–44
		First bloom	Full bloom			1939–43	1939–44	
Koto......	842	June 2	June 10	22	54.0	10.2	9.2	85
Bison......	389	June 2	June 13	22	52.3	9.6	8.4	85
Linota.....	244	June 2	June 9	23	53.1	9.3	8.3	86
Redwing...	320	May 30	June 6	20	53.8	8.3	7.6	87
Golden Sel.	976	June 2	June 11	18	54.3	8.2	—	76*
Golden.....	644	May 30	June 7	16	52.8	5.3	4.8	76

*Not tested in 1944, comparable average for Linota was 85%

EFFECT OF SEED TREATMENT ON EMERGENCE

In 1943, at Manhattan, seed of the brown-seed varieties Linota and Bison, and of the yellow-seed variety Viking were treated with New Improved Ceresan, DuBay 1452-F, Arasan, and Spergon, and planted in the field (Table 5). Seed of Linota, Bison, and Viking, with average germinations in the laboratory of 97, 95, and 86% had average seedling emergences of 75, 58, and 25%, respectively, in the field. Treating the seed with each of the fungicides gave increases in emergence. For the variety Bison, each of the fungicides gave a significant increase in emergence. For Viking, significant increases were obtained with each of the fungicides except Spergon.

In 1944, at Manhattan, seed of the brown-seed varieties Linota (four lots), Bison (three lots), and Redwing, and the yellow-seed varieties Viking and B. Golden were treated with the same fungicides

TABLE 5.—*Effect of treating flax seed with different fungicides on emergence, Manhattan and Thayer, Kans., 1943–45.*[1]

Treatment	Oz. per bu.	Percentage emergence (seedling stand)				
		Linota	Bison	Red-wing	Viking	B. Golden
		Manhattan, 1943				
Seed laboratory germination	—	97	95	—	86	—
Untreated	—	75	58	—	25	—
New Improved Ceresan	½	83	85**	—	46*	—
DuBay 1452-F	½	81	78**	—	47*	—
Arasan	2	79	78**	—	42*	—
Spergon	3	79	82**	—	37	—
		Manhattan, 1944[2]				
Seed laboratory germination	—	86	80	89	73	84
Untreated	—	41	34	40	19	29
New Improved Ceresan	½	49***	39***	52*	24	38*
DuBay 1452-F	½	48***	39***	46	22	40**
Arasan	2	44*	43***	50*	24	40**
Spergon	3	47***	41***	48	28*	40**
		Thayer, 1944				
Seed laboratory germination	—	88	86			84
Untreated	—	24	35	—	—	9
New Improved Ceresan	½	45	39	—	—	22
DuBay 1452-F	½	27	58**	—	—	20
Arasan	2	44	53	—	—	13
Spergon	3	33	49	—	—	28**
		Manhattan, 1945				
Seed laboratory germination	—	59	54	76	—	—
Untreated	—	14	19	28	—	—
New Improved Ceresan	½	18	23	47*	—	—
New Improved Ceresan	1	22*	36*	50**	—	—
DuBay 1452-F	½	16	23	41	—	—
DuBay 1452-F	1	20	35*	48*	—	—
Arasan	2	21	33	48*	—	—
Spergon	3	25**	34*	48*	—	—
Phygon	2	26**	34*	45*	—	—
		Thayer, 1945				
Seed laboratory germination	—	59	54	76	—	—
Untreated	—	16	13	39	—	—
New Improved Ceresan	½	23	22**	41	—	—
New Improved Ceresan	1	23	22**	46	—	—
Arasan	2	19	24**	39	—	—
Spergon	3	18	23**	36	—	—

[1]Planted in the field; 200 seed to 8 feet; randomized; four replications.
[2]Four different seed lots of Linota and three different seed lots of Bison were used at Manhattan, Kans., in 1944.
*Significance over untreated at the 5% level.
**Significance over untreated at the 1% level.
***Significance over untreated at the 0.1% level.

and planted in the field (Table 5). Seed of Linota, Bison, and Redwing with germinations of 86, 80, and 89% in the laboratory had seedling emergences of 41, 34, and 40%, respectively, in the field. Seed of Viking and B. Golden with germinations of 73 and 84% in the laboratory had emergences of 19 and 29%, respectively, in the field. Treating the seed with each of the fungicides for each of the five varieties gave increases in emergence. Significant increases were obtained with New Improved Ceresan, Arasan, and Spergon for four of the five varieties, while significant increases were obtained with DuBay 1452–F for three of the five varieties.

In 1944, at Thayer, seed of the varieties Linota, Bison, and B. Golden with germinations of 88, 86, and 84% in the laboratory had seedling emergences of 24, 35, and 9%, respectively, in the field (Table 5). Increases in emergence were obtained for each of the fungicide treatments for each of the three varieties. Significant increases were obtained with Bison treated with DuBay 1452–F and with B. Golden treated with Spergon.

In 1945, at Manhattan, seed of the varieties Linota, Bison, and Redwing with germinations of 59, 54, and 76% in the laboratory had seedling emergences of 14, 19, and 28%, respectively, in the field (Table 5). In addition to the fungicide treatments used in 1943 and 1944, the treatments New Improved Ceresan at 1 ounce, DuBay 1452–F at 1 ounce, and Phygon at 2 ounces per bushel were compared. All of the seed treated with fungicides gave increases in emergence. Significant increases in emergence were obtained with each of the fungicides for one or more of the varieties, except DuBay 1452–F at ½ ounce. New Improved Ceresan and DuBay 1452–F at 1 ounce per bushel gave greater increases in stand for each of the varieties than at ½ ounce per bushel.

In 1945, at Thayer, seed of Linota, Bison, and Redwing with laboratory germinations of 59, 54, and 76% had seedling emergences of 16, 13, and 39%, respectively (Table 5). Each of the fungicides for each of the varieties gave increases in emergence, and for Bison such increases were significant. Seed treated with New Improved Ceresan at 1 ounce had the same emergence for Linota and Bison and an increase in emergence for Redwing.

During the years 1943 to 1945 at Manhattan and Thayer, the treatments New Improved Ceresan (½ ounce), Arasan, and Spergon were included in 22 tests with 88 replications, while DuBay 1452–F (½ ounce) was included in 19 tests with 78 replications. These fungicides were about equally effective in increasing the emergence of seedlings over the untreated by 30, 29, 30, and 26%, respectively. In six tests with 24 replications, New Improved Ceresan at ½ ounce and 1 ounce per bushel increased the emergence of seedlings by 35 and 54%, respectively. The increase in emergence for the higher rate over the lower rate of treatment was significant. Greater increases in yield for higher rates of treatment with New Improved Ceresan are in conformity with results of the cooperative seed treatment tests in northern United States and Canada (9, 10, 12).

The average decreases in emergence of untreated seed as compared with viable seed based on laboratory germination for the varieties

Linota, Bison, and Redwing were 56, 57, and 55%, respectively, and for Viking and B. Golden 72 and 77%, respectively.

The average increases in emergence of seed treated with New Improved Ceresan at ½ ounce per bushel over untreated for Linota, Bison, and Redwing were 28, 31, and 31%, respectively. The average increases for the yellow-seed varieties Viking and B. Golden were 59 and 58%, respectively. These results are in conformity with those of other investigators (10, 16).

EFFECT OF SEED TREATMENT ON YIELD

Seed of the varieties Linota and Bison with laboratory germinations of 59 and 54%, respectively, were treated with New Improved Ceresan at ½ ounce and 1 ounce per bushel and planted at Thayer, Kans., in 1945 (Table 6). The average increases in yield for seed treatment were 1.8 and 2.7 bushels, respectively. The increase for the ½ ounce rate was significant over the untreated, and the 1-ounce rate was significant over the treatment at ½ ounce per bushel.

TABLE 6.—*Effect of treating flax seed on yield, Thayer, Kans., 1945–46.*[1]

Treatment	Oz. per bu.	Yield, bu. per acre			
		Linota	Bison	Koto	Mean
1945					
Untreated	—	6.8	9.1	—	8.0
New Improved Ceresan	½	9.3	10.3	—	9.8*
New Improved Ceresan	1	10.5*	10.9	—	10.7**
1946					
Untreated	—	7.5	8.9	8.7	8.4
New Improved Ceresan	½	7.4	10.3	8.4	8.7
New Improved Ceresan	1	8.0	9.7	8.9	8.9

[1]Planted in the field; rod rows; randomized; five replications.
*Significance over untreated at the 5% level.
**Significance over untreated at the 1% level.

In 1946, seed of the varieties Linota, Bison, and Koto with laboratory germinations of 99, 91, and 95%, respectively, were treated with New Improved Ceresan at ½ ounce and 1 ounce per bushel and planted in the field at Thayer, Kans. (Table 6). The average increases in yield for the treatments at ½ ounce and 1 ounce per bushel were 0.3 and 0.5 bushel per acre, respectively. The average increase for the two years was significant for the treatment at 1 ounce per bushel but not at ½ ounce per bushel.

The smaller increases in yield of treated over untreated flax seed in 1946 as compared with 1945 may be explained in part by the use of seed with higher germination, and in part on ideal weather conditions at planting time in 1946 as compared with moderate weather conditions in 1945.

SUMMARY

The viability of Kansas-grown flax seed, some causes of low germination, and the effect of treating seed on emergence and yield have been discussed.

A review of the literature reveals that several factors may influence viability of the seed, including weather conditions during the ripening and harvesting season, method of harvesting, stage of development when harvested, moisture content and temperature in storage, quality of the seed, degree of mechanical injury, embryo exposure, age, presence of seed-borne and soil-borne disease organisms, fungicide seed treatment, and the genetic constitution of the variety.

Results on 2,049 farm samples showed an annual variation in the average germination of 18%. Wet weather in July and early August and delay in harvesting were related to low germination.

Germination of Linota and Redwing seed was significantly higher than that of Bison or Viking. Samples of Bison contained significantly more broken seeds and impurities than Linota and Redwing in 1943, but the data were not conclusive in 1942 and 1944.

Tests on varieties grown in experimental plots showed that Linota and Redwing were superior in germination to Bison and the yellow-seed varieties. Field stands frequently were poorer from the yellow-seed varieties and this was related to lower yields.

New Improved Ceresan, DuBay 1452–F, Arasan, Spergon, and Phygon significantly increased the emergence of flax seedlings. New Improved Ceresan and DuBay 1452–F were significantly more effective in increasing emergence at the rate of 1 ounce than at ½ ounce per bushel. The yellow-seed varieties Viking and B. Golden gave greater increases in emergence as a result of treating the seed than the brown-seed varieties Linota, Bison, and Redwing. Linota had the least, but nevertheless a significant, increase in emergence following treatment.

New Improved Ceresan at ½ ounce and 1 ounce per bushel significantly increased the yield of flax in the 1945 tests. The fungicide was significantly more effective at 1 ounce than at ½ ounce per bushel. Small increases occurred in the 1946 tests when conditions seemed ideal for establishment of stands.

LITERATURE CITED

1. BURNETT, L. C., and REDDY, CHAS. S. Seed-treatment and date-of-sowing experiments with six varieties of flax. Phytopath., 21:985–989. 1931.
2. DAVIDSON, F. E., and LAUDE, H. H. Flax production in Kansas. Kans. Agr. Exp. Sta. Circ. 191. 1938.
3. DECKER, ANNA E., and REITZ, L. P. Germination tests with flax stored at different moisture and temperature levels. In press. Proceedings of the International Seed Testing Assoc., Copenhagen.
4. DILLMAN, A. C. Daily growth and oil content of flax seeds. Jour. Agr. Res., 37: 357–377. 1928.
5. ———— and STOA, T. E. Flax seed production in the north central states. U. S. D. A. Farmers' Bul. 1747. 1942.
6. ———— and TOOLE, E. H. Effect of age, condition and temperature on the germination of flax seed. Jour. Amer. Soc. Agron., 29:23–29. 1937.
7. FLOR, H. H. Flax seed-treatment tests. Phytopath., 26:429–438. 1936.

8. FORSYTH, DWIGHT D., and VOGEL, O. A. Effect of seed coat injuries during threshing on emergence of flax seedlings. Jour. Amer. Soc. Agron., 37:387–393. 1945.
9. GREANY, F. J. Cooperative flax seed treatment tests in 1944. U. S. D. A. Plant Dis. Reporter, Suppl. 159:215–219. 1945.
10. ————. Cooperative flax seed treatment tests in 1945. U. S. D. A. Plant Dis. Reporter, 30:113–119. 1946.
11. LANDON, I. K. Flax production in Kansas. Kans. Agr. Exp. Sta. Circ. 173. 1934.
12. MACHACEK, J. B. Cooperative flax seed treatment tests in 1946. Mimeographed. Seed Treatment Committee, Amer. Phytopath. Soc. 1946.
13. ———— and BROWN, A. M. Threshing injury to flax seed in Canada. Sci. Agri., 25:601–625. 1945.
14. MOORE, M. B. Coordinated small grain seed treatment tests in 1940, 1941, and 1942. Mimeographed. Seed Treatment Committee, American Phytopathological Society. 1942.
15. ———— and CHRISTENSEN, J. J. Natural and mechanical injury in flax in relation to seed treatment. (Abstract) Phytopath., 33:1117. 1943.
16. REDDY, CHAS. S., and BURNETT, L. C. Flax as an Iowa crop. Iowa Agr. Exp. Sta. Bul. 344. 1938.
17. ROBINSON, BRITTAIN B. The time to harvest fiber flax. U. S. D. A. Tech. Bul. 236. 1931.
18. SCHUSTER, MAX L., FORSYTH, DWIGHT D., and HARRAR, J. G. Influence of certain diseases and threshing injury on flax stands in Washington. Wash. Agr. Exp. Sta. V-Circ. 8. 1943.
19. STEVENS, O. A. Germination studies on aged and injured seeds. Jour. Agr. Res., 51:1093–1106. 1935.
20. SYLVÉN, NILS. Einige Spaltungszahlen bei Kreuzungen zwischen blauund weissblühenden Varietäten von *Linum usitatissimum*. Hereditas, 7:75–101. 1925–26.
21. TAMMES, TINE. The genetics of the genus *Linum*. Bibliog. Gen., 4: 1–36. 1928.
22. TERVET, IAN W. An experimental study of some fungi injurious to seedling flax. Phytopath., 27:531–546. 1937.

The Fertilizer Effectiveness of Liquid Orthophosphoric Acid[1]

W. H. MacIntire, S. H. Winterberg, L. B. Clements, and H. S. Johnson, Jr.[2]

THE practice of the direct incorporation of fertilizers in liquid form has reached substantial porportions in certain locales of the humid region of the United States. The wide adaptation of the usage of liquid manures has been prophesied and several equipments for such usage have been developed by experiment station and individual engineers. The admissibility of the incorporation of ammonia water as a source of nitrogen to nonlegumes in acidic soils and in those limestoned was dealt with in the report of a pot culture study conducted at the Tennessee Station.[3] Several devices have been developed for the drilling of ammonia, as such, and as ammonium hydroxide. The introduction of anhydrous ammonia into soils is said to have reached substantial proportions, especially in Mississippi.[4]

The chemical behavior of liquid phosphoric acid after its incorporation into soils has been studied in lysimeter experiments at the Tennessee Station during the past 12 years. The unpublished findings dealt with the distinctive exchange effects induced by the acidic forms of PO_4 in contrast to the effects induced by the binary and tertiary phosphates of calcium. The additions of H_3PO_4 have not effectuated any increase in the outgo of bases. Only recently, however, have those particular studies been amplified to include the response by plants to inputs of H_3PO_4. So far as known to the authors, there has been no report as to the admissibility and fertilizer effectiveness of H_3PO_4 incorporations. The present contribution stems from a comprehensive series of pot cultures in which solutions of that acid were incorporated in three concentrations, in three modes, and at two rates, in comparisons with the "available" P_2O_5 content of Wilson Dam concentrated superphosphate. The comparisons were based upon the growth and P_2O_5 content of rye grass and red clover and P_2O_5 recovery.

EXPERIMENTAL

Phosphatic materials.—The c.p. 85% phosphoric acid (H_3PO_4) was used in dilutions of 1 part acid and 1 part water, 1 part acid and 4 parts water, and 1 part acid and 9 parts water. The superphosphate control (S–1091) was a Wilson Dam product of 45.5% P_2O_5 content. The incorporations were upon the basis of 43.5% "available" content.

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[3]MacIntire, W. H., Winterberg, S. H., Dunham, H. W., and Clements, L. B. Response of Sudan grass to ammonium hydroxide in pot cultures. Soil Sci. Soc. Amer. Proc., 8:205–210. 1945.

[4]Andrews, W. B., Edwards, F. E., and Hammons, J. G. Ammonia as a source of nitrogen. Miss. State College preliminary report. May 1947.

TABLE 1.—*The effectiveness of H_3PO_4 in comparison with superphosphate as registered by growth and P_2O_5 content of, and recovery by, rye grass grown on Fullerton silt loam.*

Type of phosphate	Cutting	Incorporated with upper half				Layer placement 2 inches below the surface				Top-dressed after seeding			
		Dry weight, grams	P_2O_5			Dry weight, grams	P_2O_5			Dry weight, grams	P_2O_5		
			Content, %	Recovery			Content, %	Recovery			Content, %	Recovery	
				%	Lbs.			%	Lbs.			%	Lbs.
		P_2O_5 Addition, 80 Pounds											
Superphosphate	First	13.8	0.50	17.6	14.1	15.3	0.47	18.5	14.8	14.9	0.60	24.0	19.2
	Second	24.5	0.21	10.9	8.7	24.7	0.18	8.7	7.0	24.2	0.21	10.7	8.6
	Total	38.3		28.5	22.8	40.0		27.2	21.8	39.1		34.7	27.8
H_3PO_4 (1+1)	First	13.7	0.46	15.7	12.5	14.3	0.41	14.3	11.4	15.3	0.52	20.9	16.7
	Second	23.1	0.20	9.2	7.4	22.9	0.16	6.2	5.0	22.1	0.18	7.2	5.8
	Total	36.8		24.9	19.9	37.2		20.5	16.4	37.4		28.1	22.5
H_3PO_4 (1+4)	First	13.6	0.47	16.0	12.8	14.1	0.45	15.8	12.6	16.2	0.52	22.3	17.8
	Second	24.0	0.18	8.3	6.6	21.9	0.17	6.4	5.1	22.3	0.23	10.8	8.6
	Total	37.6		24.3	19.4	36.0		22.2	17.7	38.5		33.1	26.4
H_3PO_4 (1+9)	First	13.8	0.49	17.1	13.7	15.6	0.40	15.5	12.4	16.3	0.53	23.0	18.4
	Second	22.1	0.21	9.3	7.4	21.0	0.20	7.9	6.3	24.0	0.17	7.5	6.0
	Total	35.9		26.4	21.1	36.6		23.4	18.7	40.3		30.5	24.4

P_2O_5 Addition, 160 Pounds													
Superphosphate	First	16.4	0.57	12.6	20.2	17.0	0.58	13.4	21.4	16.6	0.81	19.1	30.6
	Second	27.3	0.23	7.2	11.5	26.4	0.23	6.9	11.0	27.2	0.27	8.9	14.2
	Total	43.7		19.8	31.7	43.4		20.3	32.4	43.8		28.0	44.8
H_3PO_4 (1+1)	First	14.9	0.53	10.4	16.6	15.4	0.50	10.0	16.0	16.5	0.69	15.8	25.3
	Second	25.7	0.23	6.6	10.6	23.9	0.21	5.2	8.3	26.2	0.23	6.8	10.9
	Total	40.6		17.0	27.2	39.3		15.2	24.3	42.7		22.6	36.2
H_3PO_4 (1+4)	First	14.8	0.56	11.0	17.6	15.8	0.53	11.1	17.8	16.8	0.69	16.1	25.8
	Second	28.6	0.22	7.2	11.5	23.6	0.21	5.1	8.2	25.1	0.25	7.2	11.5
	Total	43.4		18.2	29.1	39.4		16.2	26.0	41.9		23.3	37.3
H_3PO_4 (1+9)	First	15.2	0.56	11.3	18.1	14.9	0.56	11.0	17.6	17.4	0.64	15.4	24.6
	Second	27.6	0.25	8.2	13.1	25.3	0.24	6.9	11.0	24.8	0.23	6.3	10.1
	Total	42.8		19.5	31.2	40.2		17.9	28.6	42.2		21.7	34.7
No P_2O_5													
None	First	3.5	0.37	—	—	—	—	—	—	—	—	—	—
	Second	9.9	0.17	—	—	—	—	—	—	—	—	—	—
	Total	13.4	—	—	—	—	—	—	—	—	—	—	—

Soil.—Fullerton silt loam.

Crops.—Rye grass on unlimed soil, pH 5.2; red clover on limestoned soil, pH 7.2.

Rates.—Basis of pounds per acre surface: P_2O_5, 80 and 160 pounds; K_2SO_4, 370 pounds, or 200 pounds of K_2O; limestone, 3,000 pounds, $CaCO_3$ equivalence; magnesium, 60 pounds of MgO as $MgSO_4 \cdot 7H_2O$; ammonium nitrate, sufficient for maximal growth of rye grass.

Incorporations and applications.—The H_3PO_4 solutions and superphosphate were applied as specified in the tables; K_2SO_4, limestone, and magnesium sulfate into upper half of soil; ammonium nitrate was top dressed.

Aging.—The limestoned soil was aged 2 weeks prior to the incorporation of the other fertilizer materials.

PLANT RESPONSES

A significant increase by rye grass response, and in its P_2O_5 content, was induced by the addition of either phosphoric acid solution or superphosphate (Table 1 and Fig. 1).

In general, the growth of the first cutting of rye grass was virtually the same for a given comparison of H_3PO_4 and superphosphate, and likewise for the second cutting which was almost double that of the first.

The layer placement and top-dressing of both phosphates proved somewhat more effective than from the upper-half incorporations when the P_2O_5 input was at the 80-pound rate. In most instances,

TABLE 2.—*The effectiveness of H_3PO_4 in comparison with superphosphate as registered by growth of, and P_2O_5 recovery by, rye grass grown on Fullerton silt loam.*

Type of phosphate	P_2O_5 additions, 80 pounds				P_2O_5 additions, 160 pounds			
	Dry weight, grams	Relative index	P_2O_5 recovery, %	Relative index	Dry weight, grams	Relative index	P_2O_5 recovery, %	Relative index
				Incorporated With Upper Half				
Superphosphate......	38.3	100	28.5	100	43.7	100	19.8	100
H_3PO_4 (1+1)	36.8	96	24.9	87	40.6	93	17.0	86
H_3PO_4 (1+4)	37.6	98	24.3	85	43.4	99	18.2	92
H_3PO_4 (1+9)	35.9	94	26.4	93	42.8	98	19.5	98
				Layer Placement 2 Inches Below Surface				
Superphosphate......	40.0	104	27.2	95	43.4	99	20.3	103
H_3PO_4 (1+1)	37.2	97	20.5	72	39.3	90	15.2	77
H_3PO_4 (1+4)	36.0	94	22.2	78	39.4	90	16.2	82
H_3PO_4 (1+9)	36.6	96	23.4	82	40.2	92	17.9	90
				Top-dressed After Seeding				
Superphosphate......	39.1	102	34.7	122	43.8	100	28.0	141
H_3PO_4 (1+1)	37.4	98	28.1	99	42.7	98	22.6	114
H_3PO_4 (1+4)	38.5	101	33.1	116	41.9	96	23.3	118
H_3PO_4 (1+9)	40.3	105	30.5	107	42.2	97	21.7	110

this was also true for H_3PO_4 at the 160-pound rate. The second cutting showed virtually equal response to the three modes of incorporation at both rates.

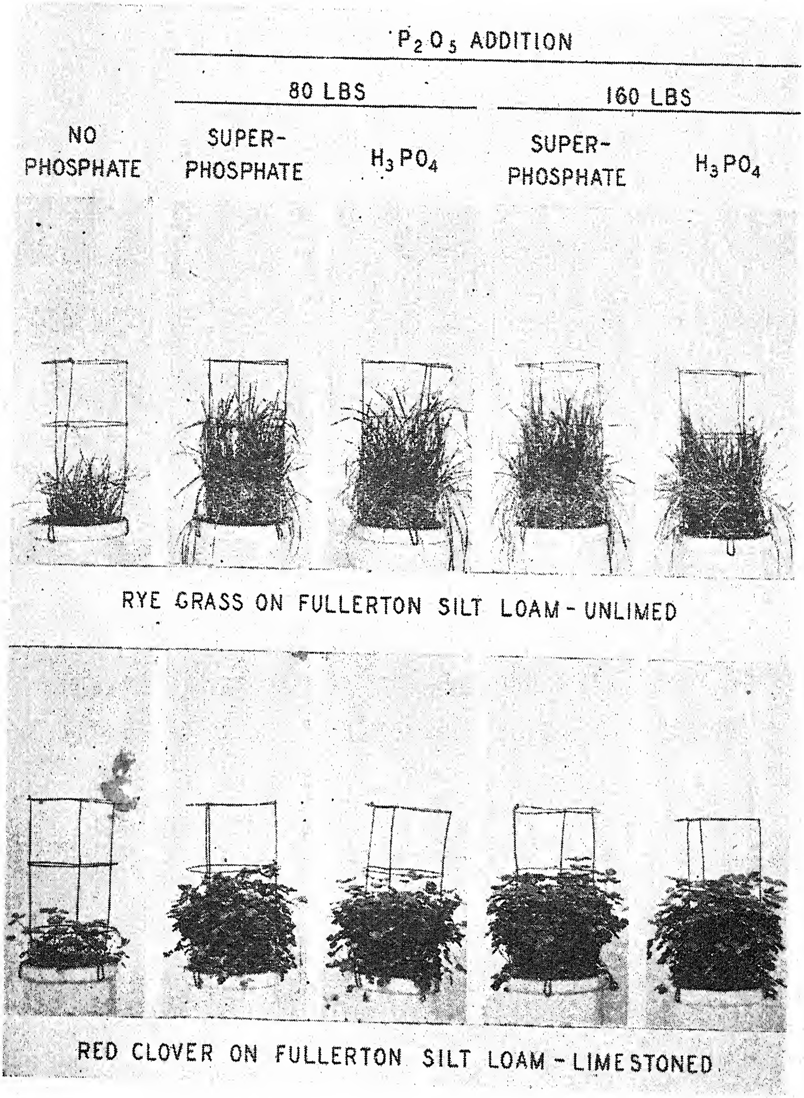

FIG. 1.—Crop response to upper-half incorporations of H_3PO_4 (1+4) and superphosphate (45% P_2O_5).

The P_2O_5 content of the rye grass was increased significantly by the addition of either H_3PO_4 or superphosphate. By doubling the rate of P_2O_5 input from 80 pounds to 160 pounds, P_2O_5 content also was

TABLE 3.—*The effectiveness of H_3PO_4 in comparison with superphosphate as registered by growth and P_2O_5 content of, and recovery by, red clover grown on Fullerton silt loam.*

Type of phosphate	Cutting	Incorporated with upper half				Layer placement 2 inches below the surface				Top-dressed after seeding			
		Dry weight, grams	P_2O_5			Dry weight, grams	P_2O_5			Dry weight, grams	P_2O_5		
			Content, %	Recovery			Content, %	Recovery			Content, %	Recovery	
				%	Lbs.			%	Lbs.			%	Lbs.
P_2O_5 Addition, 80 Pounds													
Superphosphate	First	19.8	0.34	18.6	14.9	20.0	0.36	20.0	16.0	17.1	0.44	21.0	16.8
	Second	16.5	0.30	12.7	10.2	16.7	0.30	12.9	10.3	14.8	0.37	14.4	11.5
	Total	36.3		31.3	25.1	36.7		32.9	26.3	31.9		35.4	28.3
H_3PO_4 (1+1)	First	18.0	0.34	16.7	13.4	19.0	0.34	17.7	14.2	17.7	0.37	18.0	14.4
	Second	14.1	0.32	11.3	9.0	14.0	0.31	10.8	8.6	15.0	0.31	14.9	11.9
	Total	32.1		28.0	22.4	33.0		28.5	22.8	32.7		32.9	26.3
H_3PO_4 (1+4)	First	18.5	0.34	17.2	13.8	19.2	0.34	17.9	14.3	17.7	0.39	19.1	15.3
	Second	13.3	0.33	10.9	8.7	14.6	0.30	10.9	8.7	15.0	0.31	14.9	11.9
	Total	31.8		28.1	22.5	33.8		28.8	23.0	32.7		34.0	27.2
H_3PO_4 (1+9)	First	19.9	0.37	20.5	16.4	18.3	0.37	18.7	15.0	17.7	0.40	19.7	15.8
	Second	15.5	0.32	12.7	10.2	14.6	0.31	11.4	9.1	15.8	0.31	12.5	10.0
	Total	35.4		32.2	26.6	32.9		30.1	24.1	33.5		32.2	25.8

						P_2O_5 Addition, 160 Pounds							
Superphosphate	First	23.9	0.46	16.0	25.6	22.6	0.44	14.3	22.9	20.2	0.44	12.7	20.3
	Second	21.1	0.46	13.8	22.1	19.7	0.40	10.8	17.3	18.7	0.40	10.3	16.5
	Total	45.0		29.8	47.7	42.3		25.1	40.2	38.9		23.0	36.8
H_3PO_4 (1+1)	First	22.5	0.45	14.6	23.4	22.2	0.41	13.0	20.8	20.9	0.45	13.5	21.6
	Second	18.8	0.44	11.6	18.6	18.8	0.37	9.5	15.2	18.6	0.38	9.7	15.5
	Total	41.3		26.2	42.0	41.0		22.5	36.0	39.5		23.2	37.1
H_3PO_4 (1+4)	First	21.9	0.44	13.8	22.1	20.3	0.44	12.7	20.3	22.6	0.44	14.3	22.9
	Second	19.1	0.44	11.8	18.9	18.4	0.38	9.6	15.4	18.7	0.37	9.4	15.0
	Total	41.0		25.6	41.0	38.7		22.3	35.7	41.3		23.7	37.9
H_3PO_4 (1+9)	First	22.5	0.46	15.0	24.0	20.5	0.43	12.6	20.2	21.9	0.43	13.5	21.6
	Second	18.9	0.45	11.9	19.0	17.8	0.38	9.2	14.7	18.2	0.37	9.1	14.6
	Total	41.4		26.9	43.0	38.3		21.8	34.9	40.1		22.6	36.2
						No P_2O_5							
None	First	3.5	0.23	—	—	—	—	—	—	—	—	—	—
	Second	3.9	0.23	—	—	—	—	—	—	—	—	—	—
	Total	7.4	—	—	—	—	—	—	—	—	—	—	—

enhanced. The outstanding feature of the data is the high P_2O_5 content of the first cutting of rye grass where the phosphates were top-dressed after seeding. In most cases the P_2O_5 content from the top-dressing was considerably higher than that from either the upper-half incorporation or the layer placement 2 inches below the surface. It is also significant that the P_2O_5 content of the crop was higher from the superphosphate than from the H_3PO_4 at either of its dilutions.

Percentage content of P_2O_5 in the second cutting of rye grass was virtually the same for the 80-pound input, regardless of mode of incorporation and this was also true for the 160-pound rate. The P_2O_5 percentage content and recoveries were much higher for the first cutting than for the second. As in the case of the P_2O_5 content, the percentage and pounds of P_2O_5 recovered were largest where the phosphates were top-dressed after seeding. The data show that a higher percentage of P_2O_5 recovery was from the 80-pound addition, but in actual pounds recovery was larger from the 160-pound addition.

In the formulations of Table 2, the dry weight, and likewise P_2O_5 recovery, from superphosphate was assigned the value of 100 for the phosphate incorporations within the upper half at the rates of 80 pounds and 160 pounds of P_2O_5 input.

Upon basis of dry weight, total growth shows virtually the same for the two forms of phosphate at the 80-pound rate, regardless of the mode of incorporation.

Upon basis of P_2O_5 recovered, however, the relative index shows that where the H_3PO_4 was incorporated with the upper half or placed in a layer 2 inches below the surface, the P_2O_5 recovery was much less than that from superphosphate. The percentage recoveries of P_2O_5 from the H_3PO_4 and superphosphate top-dressings were considerably more than those from the upper-half incorporations.

The relative index of the dry weight shows that at the rate of 160 pounds of P_2O_5 input the incorporations of H_3PO_4 into the upper half were equally effective with the top dressings, whereas in the layer placement the H_3PO_4 was less effective than the superphosphate.

In dry weight the first cutting of red clover responded virtually alike to the two forms of phosphate, at the 80-pound and 160-pound rates of P_2O_5 input, regardless of mode of addition (Table 3 and Fig. 1). The same can be said for the second cutting, although growth was slightly less than that of the first cutting.

The P_2O_5 content of the first cutting was slightly higher where the phosphates were top-dressed after seeding, and was highest where the superphosphate was added. Phosphate content also was increased by doubling the rate of P_2O_5 input. At the heavier rate for P_2O_5 input the modes of additions induced virtually the same P_2O_5 content.

The P_2O_5 content of the second cutting of red clover was virtually the same for the 80-pound P_2O_5 rate, regardless of mode of addition. The data indicated, however, that for the 160-pound input the highest P_2O_5 content was obtained where the phosphates were incorporated with the upper half of the soil. In all cases, the P_2O_5 content of the second cutting of red clover was lower than for the content of the first cutting, but the difference was not great.

Upon basis of dry weight (Table 4), response was not the same for the two types of phosphate when the P_2O_5 input was at the 80-pound rate. In general, the H_3PO_4 index was close to 90, as compared to 100 for superphosphate, except for the value of 88 where the superphosphate was top-dressed.

TABLE 4.—*The effectiveness of H_3PO_4 in comparison with superphosphate as registered by growth of, and P_2O_5 recovery by, red clover grown on Fullerton silt loam.*

Type of phosphate	P_2O_5 additions, 80 pounds				P_2O_5 additions, 160 pounds			
	Dry weight, grams	Relative index	P_2O_5 recovery, %	Relative index	Dry weight, grams	Relative index	P_2O_5 recovery, %	Relative index
Incorporated With Upper Half								
Superphosphate......	36.3	100	31.3	100	45.0	100	29.8	100
H_3PO_4 (1+1)	32.1	88	28.0	89	41.3	92	26.2	88
H_3PO_4 (1+4)	31.8	88	28.1	90	41.0	91	25.6	86
H_3PO_4 (1+9)	35.4	98	32.2	103	41.4	92	26.9	90
Layer Placement 2 Inches Below Surface								
Superphosphate......	36.7	101	32.9	105	42.3	94	25.1	84
H_3PO_4 (1+1)	33.0	91	28.5	91	41.0	91	22.5	76
H_3PO_4 (1+4)	33.8	93	28.8	92	38.7	86	22.3	75
H_3PO_4 (1+9)	32.9	91	30.1	96	38.3	85	21.8	73
Top-dressed After Seeding								
Superphosphate......	31.9	88	35.4	113	38.9	86	23.0	77
H_3PO_4 (1+1)	32.7	90	32.9	105	39.5	88	23.2	78
H_3PO_4 (1+4)	32.7	90	34.0	109	41.3	92	23.7	80
H_3PO_4 (1+9)	33.5	92	32.2	103	40.1	89	22.6	76

The general relationship that obtained for the dry weight was true also for P_2O_5 recoveries where the phosphates were incorporated with the upper half of soil and where placement was in the layer. The top-dressing of the phosphates showed up significantly, however, in the percentage of P_2O_5 recovered.

The growth from the 160-pound input of P_2O_5 was greatest where the phosphates were incorporated with the upper half, the index for the H_3PO_4 being 92 against 100 for the superphosphate. Plant response to the upper half incorporation was better than the response to the layer placement and to the top-dressing of either H_3PO_4 or superphosphate.

The P_2O_5 recovery from the 160-pound input as H_3PO_4 was considerably less than the recovery from superphosphate when incorporations were in the upper half. All recoveries from the layer placement and from the top-dressings of both the H_3PO_4 and the superphosphate were much less than the recoveries from the upper half incorporation.

GENERAL OBSERVATIONS

Used to supply "available" P_2O_5 at 80- and 160-pound rates, no effect upon soil pH was registered by samples of soil into which the H_3PO_4 and the superhosphate incorporations had been made in the upper half.

Variance in the dilution of the H_3PO_4 did not result in significant difference in crop response, in P_2O_5 content, or in P_2O_5 recovery, regardless of rate of addition or mode of incorporation.

The rye grass gave slightly more response to a given treatment, but the clover gave a larger recovery of P_2O_5.

SUMMARY

Additions of liquid phosphoric acid (H_3PO_4) were made to pot cultures in three concentrations, under three modes of incorporation, in parallel with additions of superphosphate, all of which caused increases in growth of rye grass and of red clover, and without adverse effect upon germination.

Measured by response and by P_2O_5 content and by P_2O_5 recovery in rye grass and in red clover, the H_3PO_4 was slightly less effective than superphosphate.

Differential dilution of H_3PO_4—1+1, 1+4, and 1+9—did not result in significant differences in crop response or in the P_2O_5 content of the crops.

The top-dressing of H_3PO_4, and of superphosphate, induced increases in rye grass growth and in the P_2O_5 recovery from the 80- and the 160-pound inputs. The same was true of the red clover when the rate for P_2O_5 input was 80 pounds, but not when the rate was 160 pounds.

Influence of Some Perennial Grasses on the Organic Matter Content and Structure of an Eastern Nebraska Fine-Textured Soil[1]

J. R. McHenry and L. C. Newell[2]

THE effects of perennial sod crops on the chemical and physical properties of soils have been the subject of much discussion and speculation (1, 9).[3] Various authors, particularly Russian workers (3, 4, 13), have indicated the desirable effects that perennial grasses may have on the physical and chemical properties of soil. Other workers have indicated skepticism as to the beneficial effects of a perennial grass on soil structure (2, 12), and still others report data of an inconclusive nature (6).

It is believed that a suitable perennial grass has a place in the cropping systems on the soils of eastern Nebraska. Many of these soils occur on gently rolling to rolling topography where erosion is moderate to severe. In the most severe cases, erosion has already proceeded to such a degree that the establishment of a grass cover presents grave problems. In the less severe cases, a change in the cropping systems which would afford protection to such land is essential if erosion is to be controlled. The inclusion of a perennial grass in the cropping system of the area would be desirable if such a procedure was profitable and at the same time maintained the soil organic matter level and the physical condition of the soil adequately for erosion control.

It is the purpose of this paper to report the effects of several perennial grasses on the following properties of a Butler silty clay loam soil at Lincoln, Neb., from 1938 to 1945: Total nitrogen, readily oxidizable material, percentage of aggregates greater than 0.25 mm, and the percentage of pore-space saturation at a tension of 40 cm of water.

EXPERIMENTAL PROCEDURE

DESCRIPTION OF GRASS PLOTS

The design of the grass experiment with which this paper deals is described in a previous report of the effects of mowing frequency on the yields and protein content of 11 grasses (8). Newell and Keim (8) also described the methods of clipping the plots and the procedures used for determining yields. The grass experiment consisted of 12 replications of 15 plots with different grass covers. One-half of the plots, i.e., six replications, were clipped once a year to measure hay yields; the cool-season grasses being harvested in early June and the warm-season grasses being harvested in late July or August. The remaining six replications were harvested several times during the season to simulate grazing. The individual plots were 8½×70 feet in size.

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[3]Reference by numbers in parenthesis is to "Literature Cited", p. 993.

The grasses were in their fifth or seventh year of production when soil samples were taken in the summer of 1944. The following grasses had been established in rows drilled approximately 1 foot apart during the fall of 1939 and the spring of 1940: Bromegrass, *Bromus inermis* Leyss.; crested wheatgrass, *Agropyron cristatum* L. Gaertn.; western wheatgrass, *Agropyron smithii* Rydb.; and Russian wildrye, *Elymus junceus* Fisch. The western wheatgrass and bromegrass had established a solid stand, whereas the other two grasses produced their maximum yields from the spaced rows during the later years of the experiment. The older plots of grasses had been established in broadcast or close-drilled plots in the spring of 1938. The grass plots included in these seedings were as follows: Bromegrass; Kentucky bluegrass, *Poa pratensis* L.; orchard grass, *Dactylis glomerata* L.; buffalo grass, *Buchloe dactyloides* (Nutt.) Engelm.; blue grama, *Bouteloua gracilis* (H.B.K.) Lag.; side-oats grama, *Bouteloua curtipendula* (Mich.) Torr.; switchgrass, *Panicum virgatum* L.; and big bluestem, *Andropogon furcatus* Muhl.

SOIL SAMPLING

Soil samples were obtained from plots of each of the grasses and from a weedy plot which occurred in each of the replications. The series of weedy plots had originally been planted to alfalfa in the spring of 1940, but they contained less than a 10% stand of alfalfa and only a part of the stand of perennial grasses, chiefly Kentucky bluegrass. These plots were allowed to go to weeds annually. Soil samples from these plots were taken so as to avoid clumps of alfalfa or perennial grasses. In addition, samples were taken from a cultivated field adjacent to the grass plots.

Soil samples for the determination of total nitrogen and oxidizable material were taken from 13 plots in each of 12 replications at two depths, 0 to 6 inches and 6 to 12 inches. Six cores were taken at intervals of 10 feet throughout the length of each plot and composited. Care was exercised so that each core was taken from an area representative of the particular grass being sampled. The samples were removed to the laboratory, and after being broken up by hand into lumps of ½ inch diameter or less, were air-dried. They were then ground in a Braum pulverizer to pass a screen 1 mm in diameter.

Soil samples for measurements of volume weight, pore-space saturation, and aggregation were taken at depths of 1 to 3 and 5 to 7 inches from three locations in each of 13 plots of eight replications. In addition, samples were obtained at a depth of 11 to 13 inches from 13 plots of two selected replications. A soil sampler with removable sleeves was used to obtain an undisturbed core of soil 2 inches in diameter to a depth of 2 inches. The removable sampling sleeves were made from standard 4-ounce drug cartons cut to the desired length and waxed to prevent absorption of moisture. Upon removal of the sleeve containing the core of sampled soil, waxed carton covers were placed over the ends of the sleeve so that the carton served as a moisture-tight container. Prior to analysis, core samples were stored in a cool room (40° F) so that moisture loss and microbial activity were minimized.

METHODS OF ANALYSES

Total nitrogen percentages were determined on 10-gram soil samples by a slight modification of the Gunning method, about 0.1 gram of copper being used as a catalyst. Readily oxidizable organic matter was determined on 1-gram soil samples by a modification of the Walkley-Black method essentially as described by Smith and Weldon (11). Aggregates greater than 0.25 mm were measured by the wet-sieving procedure outlined by McHenry and Russell (7). Percentage saturation of pore space at a tension of 40 cm of water was determined by a modification of the Leamer and Shaw technique (5). In place of the tension table used by Leamer and Shaw, large circular porous ceramic plates were employed.[4] Moisture desorption curves were obtained for certain selected samples by Russell's technique (10).

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[4]Porous ceramic plates were obtained through the courtesy of Dr. M. B. Russell, formerly Research Professor, Iowa State College, Ames, Iowa. These plates were manufactured by the General Ceramics and Steatite Corporation, Keasbey, N. J., as item K939, 12-inch diameter.

The 2-inch undisturbed cores of soil were carefully cut into two equal sections and used for the physical measurements, the upper sections with respect to their position in the soil profile being used for the tension determinations and the lower sections being used for aggregate analyses. The samples for measurements of pore space were saturated by capillarity for a period of 4 hours, firmed into contact with the porous plate surface, and left for 24 hours at a tension of 40 cm of water. Cores placed on the individual tension plates for moisture-desorption measurements were initially saturated under reduced pressure. Successive readings at increasing tensions were taken at intervals of not less than 3 hours in order to establish conditions of moisture equilibrium.

CHARACTERISTICS OF THE GRASS SODS

The grasses exhibited varying degrees of vigor at the time of sampling. These differences resulted from the variable responses of the grasses to the climatic conditions during the preceding years and to their reaction to the clipping treatments. The period of years during which the older plots were established was hazardous from the standpoints of the lack of subsoil moisture, inadequate distribution of current rainfall, and the depredations of grasshoppers. The grasses made poor growth and the yields were very low in 1939 and 1940. With the advent of more favorable moisture conditions, the later seedings were established with less difficulty and a better growth and larger yields were produced in the subsequent years.

The cool-season grasses, bromegrass, crested wheatgrass, Russian wildrye, and Kentucky bluegrass produced sods which were seldom invaded by weeds or other perennial grasses. Bromegrass gave the best yield performance over the period of years, but the older plots exhibited tendencies toward sod binding during the last two years. Big bluestem was the highest yielding grass during the last two years but was slow in reaching that stage of productivity. Blue grama, in spite of the fact that the particular strain was a small, relatively low-yielding plant type, produced the best stands of any of the warm-season grasses. Buffalo grass produced its best growth in 1941 and 1942 but was subjected to weed invasion and loss of stand under competition following these years of favorable moisture conditions. Side-oats grama was usually invaded by weeds during the spring months, but during the latter years of the experiment produced an excellent stand and growth during the summer months. Orchard grass never produced a sufficient stand to measure its relative yielding ability adequately in comparison with the other grasses. For this reason the results presented in this paper for orchard grass are undoubtedly biased. This is particularly true in regard to nitrogen and carbon determinations because soil samples were taken in selected areas representing vigorous vegetative growth and not at random as was done in the sampling of the other plots.

INFLUENCE OF PERENNIAL GRASSES ON NITROGEN AND OXIDIZABLE MATERIAL

Data for the total nitrogen content of the soil for the 0 to 6-inch depth under the various perennial grasses are presented in Fig. 1. The values given in this figure, as well as in the following tables and figures, are grouped to show the results as influenced by age of sod and

seasonal growth habits. There is apparently no distinct difference in total nitrogen content as related to the seasonal growth habits of the several grasses. The nitrogen content appears to be a function of the individual grass and of the age of the sod. Analysis of variance for the total nitrogen data indicates the difference in nitrogen content of the soil under the various grasses is highly significant, the least significant difference being 0.0058% nitrogen at the 1% level.

All of the grass plots contained more nitrogen than the weedy check plots, the differences being significant at the 5% level for all grasses

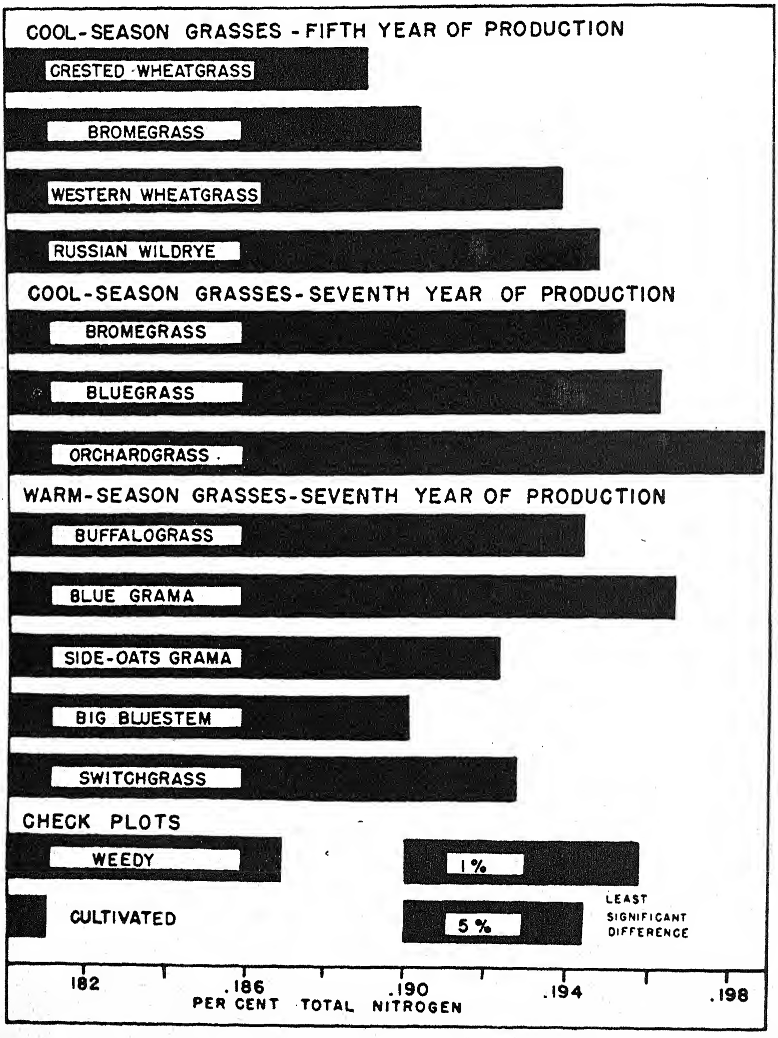

FIG. 1—Total nitrogen content of the surface 6 inches of a Butler silty clay loam soil as influenced by various perennial grasses.

except big bluestem and crested wheatgrass. The nitrogen content of the cultivated field is much less than any of the grassed plots or the weedy check. The cool-season grasses in their seventh year of production maintained the highest level of nitrogen of any of the groups. The effect of age of sod on nitrogen content may be seen from the data which indicate that the bromegrass plots in the seventh year of production were significantly higher in nitrogen content than the bromegrass plots in the fifth year of production. However, the plots in the fifth year of production of western wheatgrass and Russian wildrye contained amounts of nitrogen similar to the nitrogen contents of the bromegrass and bluegrass plots in the seventh year of production. The relatively high contents of nitrogen in the plots of the short grasses, blue grama and buffalo grass, are as expected from field observations of the growths of grasses in these plots. The switchgrass stand was deteriorating when sampled. Side-oats grama and big bluestem might have contributed larger amounts of nitrogen if they had come into maximum production earlier in the experiment.

TABLE 1.—*Effects of kind and age of grass cover on the readily oxidizable organic matter content of a Butler silty clay loam soil.*

Kind and age of grass cover	Readily oxidizable material, m.e. per gram of soil	
	0–6 in.*	6–12 in.*
Grass Plots in Fifth Year of Production		
Cool-season grasses:		
Crested wheatgrass	6.15	5.15
Bromegrass	6.14	5.23
Western wheatgrass	6.22	5.18
Russian wildrye	6.25	5.25
Grass Plots in Seventh Year of Production		
Cool-season grasses:		
Bromegrass	6.32	5.31
Bluegrass	6.30	5.16
Orchard grass	6.31	5.31
Warm-season grasses:		
Buffalo grass	6.31	5.19
Blue grama	6.51	5.39
Side-oats grama	6.27	5.28
Big bluestem	6.19	5.16
Switchgrass	6.27	5.28
Check Plots		
Weedy plot	6.05	5.05
Cultivated field	5.82†	4.79†
Least Significant Difference		
5% level	0.163	—
1% level	0.215	—

*Average of 12 plots.
†Comparison value only, not used in statistical analyses.

Table 1 and Fig. 2 present the data concerning the effects of the several perennial grasses on the readily oxidizable organic matter content of the surface 6 inches of soil. In addition, similar data are tendered in Table 1 for the 6- to 12-inch depth. Analysis of variance indicates a highly significant difference in readily oxidizable organic matter in the 0 to 6-inch depth due to the difference in perennial grass covers. The data from the cultivated check, in oats stubble

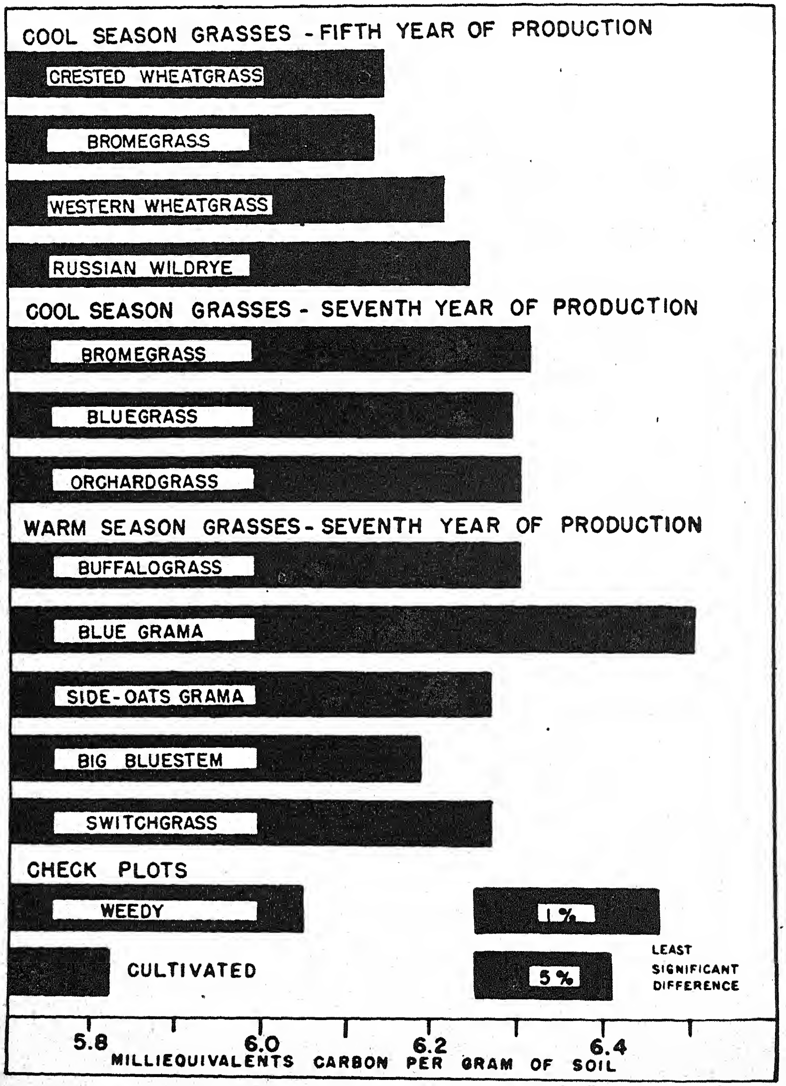

FIG. 2.—Readily oxidizable material of the surface 6 inches of a Butler silty clay loam soil as influenced by various perennial grasses.

when sampled, are included in the tables and figures for comparison but were not used in the statistical analyses. The least significant difference at the 1% level for the 0 to 6-inch depth is 0.215 m. e. of readily oxidizable material per gram of soil. There was no significant difference in readily oxidizable material due to differences in grass cover for the 6- to 12-inch depth. In all cases, highly significant differences of nitrogen content and readily oxidizable material were obtained between replications. This would indicate, as field observations verify, that the experimental area is not homogeneous with regard to the soil.

There is a large relative increase in readily oxidizable material for all grass plots over that for the cultivated field, as well as over that of the weedy check plots. This increase in readily oxidizable material is statistically significant for most of the grasses. This increased organic matter content of the sod soils may be ascribed to the increased production of perennial grasses over that of annual weeds, and to the fact that much of the vegetative organic matter had been removed during the time of the experiment from the cultivated field. This difference in content of soil organic matter for grassed and nongrassed areas, however, is apparently not related to the yields of grasses obtained. Grass yields were taken throughout the experiment (8) from all plots. Regression coefficients comparing total nitrogen with both the yields of grass in 1944 and with the average yields for 1941 and 1944 were not significant. Therefore, it appears that the effects of the grasses must be related to root production.

As would be expected, the amount of the total nitrogen in the soil is closely related to the amount of readily oxidizable organic material. The regression coefficient between the two is highly significant. It is assumed, therefore, that the two determinations measure the same soil property, soil organic matter. Total nitrogen was not determined on the 6- to 12-inch samples.

INFLUENCE OF PERENNIAL GRASSES ON SOME PHYSICAL PROPERTIES OF THE SOIL

AGGREGATION

The influence of the various perennial grasses on the percentage of water-stable aggregates in the soil greater than 0.25 mm are presented in Table 2 for depths of 1 to 3, 5 to 7, and 11 to 13 inches. Fig. 3 illustrates graphically the differences in aggregation of the soils under the different perennial grasses for the 1- to 3-inch depth. Analyses of variance for the percentage of water-stable aggregates greater than 0.25 mm under the various perennial grasses indicate a highly significant difference between grasses for the 1- to 3-inch depth, a significant difference for the 5- to 7-inch depth, and a highly significant difference for the 11- to 13-inch depth.

Although aggregation of the soil is significantly different due to grass cover, the increase in aggregation due to grass in comparison to the weedy check plot is limited to the 1- to 3-inch depth. Even then it will be noted that only four grasses have stabilized the soil aggregates to a degree significantly greater than under the annual weed cover. At

TABLE 2.—*Effects of kind and age of grass cover on the percentage of water-stable aggregates greater than 0.25 mm for a Butler silty clay loam soil.*

Kind and age of grass cover	Percentage stable aggregates greater than 0.25 mm at		
	1–3 in.*	5–7 in.*	11–13 in.†
Grass Plots in Fifth Year of Production			
Cool-season grasses:			
Crested wheatgrass	35.5	62.4	80.7
Bromegrass	36.4	65.0	87.9
Western wheatgrass	31.2	61.1	75.3
Russian wildrye	38.4	58.8	85.9
Grass Plots in Seventh Year of Production			
Cool-season grasses:			
Bromegrass	45.3	64.7	87.7
Bluegrass	45.7	59.2	90.2
Orchard grass	43.9	61.1	90.4
Warm-season grasses:			
Buffalo grass	34.1	47.6	83.4
Blue grama	48.6	65.2	79.5
Side-oats grama	52.4	65.0	82.7
Big bluestem	43.2	64.0	81.3
Switchgrass	40.1	61.5	80.3
Check Plots			
Weedy plot	38.0	65.9	88.2
Cultivated field	20.2‡	51.9‡	75.1‡
Least Significant Difference			
5% level	6.41	9.37	5.40
1% level	8.50	—	7.23

*Average of eight plots.
†Average of two plots.
‡Comparison value only, not used in statistical analyses.

the lower sampling depths a number of the samples under various grasses show a significant decrease in aggregate stability as compared with the soil under weeds. This fact is probably related to the variations within the soil itself. For the surface 1- to 3-inch depth it was assumed there would be a significant relation between organic matter and the percentage of water-stable aggregates. However, the regression coefficients for the percentages of stable aggregates greater than 0.25 mm for the 1- to 3-inch depth compared with total nitrogen and with readily oxidizable material for the 0 to 6-inch depth were not significant. When the average percentage of water-stable aggregates greater than 0.25 mm for the 1- to 3-inch and 5- to 7-inch depths is compared with the total nitrogen content, the readily oxidizable material regression coefficients are significant and highly significant, respectively. These results suggest that there is a close relationship between soil aggregation and the total nitrogen and organic matter contents.

The percentages of stable aggregates obtained with the buffalo grass plots for the 1- to 3-inch depth seem quite low. It was observed in the field that the soil under buffalo grass appeared well aggregated. In the laboratory, when the buffalo grass soil samples were subjected to wet sieving, it was observed that the aggregates appeared water-stable but were of such a size as to pass through the 0.25 mm sieve. Hence, the percentages of aggregates greater than 0.25 mm for the

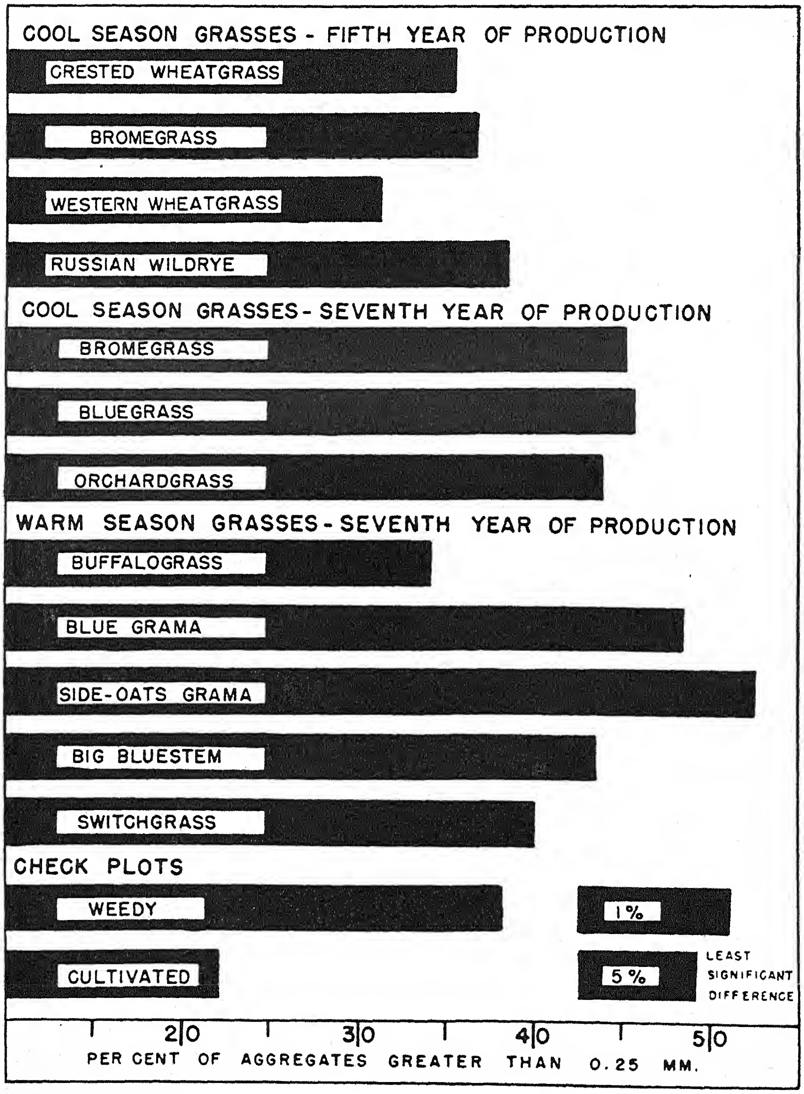

FIG. 3.—Percentage of aggregates greater than 0.25 mm in the 1- to 3-inch depth of a Butler silty clay loam soil as influenced by various perennial grasses.

buffalo grass samples are among the lower values. Apparently the root habits of the various grasses have considerable influence on the size and the stability of the soil aggregates formed under the various grasses.

If a comparison between groups of grasses as indicated in Table 2 is made, little difference is found between the cool- and warm-season grasses of comparable age. Where age of grass sod is varied (bromegrass specifically), the older sods have been more effective in producing or maintaining soil aggregates. Similar results are to be noted with respect to total nitrogen content and readily oxidizable material.

It is of interest to note in comparing aggregation and organic matter values that the regression coefficients calculated for the percentage of aggregates greater than 0.25 mm for the 1- to 3-inch and the 5- to 7-inch depths as compared with the 1944 grass yields, and the average of four years (1941–44) are not significant. The coefficients are negative indicating that as the yields increase, as measured by organic matter removal, the less in general will be the stability of the soil aggregates.

PORE-SPACE RELATIONSHIPS

A single relative measure of the distribution of the soil pores was made using a tension table and obtaining the percentage of moisture held at a tension of 40 cm of water, pF of 1.6. The percentage saturation of the pore space at this tension was calculated, using the data on volume weight and the density of the soil as 2.65. As determined, this percentage saturation measures the volume of pores of a diameter of 0.073 mm or less which are filled with water. This value is then expressed as a percentage of the total void space in the sample. As soils which contain a large percentage of their pore space as pores of small diameter are associated with poorly aggregated soils, the greater the pore space saturation value in general and the poorer the soil is in soil aggregates and other desirable physical properties.

The effects of the various perennial grasses on the percentage of pore-space saturation at a tension of 40 cm of water is presented in Table 3. The values of the 1- to 3-inch depth are also presented graphically in Fig. 4. Analyses of variance for grass cover for both the 1- to 3-inch and the 5- to 7-inch depths show no significant difference due to grass cover. For the cultivated field the data show a much higher pore-space saturation than for any of the grasses. The weedy check plot shows on the other hand the lowest percentage saturation.

It is thought that the number of samples taken was insufficient to show possible significant differences in the pore space of the various kinds of sods. The experimental error of the method of determination accounts for part of this discrepance, but the main source of error is to be found in the samples. Variations among plots are large and the number of samples necessary for determining significant differences is apparently larger than the number taken.

Volume weight determinations are presented for the 1- to 3-inch depth samples in Fig. 4. As the measure of pore space presented in this paper utilizes the volume weight data, the two are directly correlated. Volume weights for the 5- to 7-inch depth and the 11- to

13-inch depth were progressively larger and reflected in their statistical analyses the facts that the soil in the experimental area is not uniform and that the clay content increases from the surface to the depths sampled.

Moisture desorption curves were obtained for four grasses, bromegrass, big bluestem, bluegrass, and blue grama. One sample from each

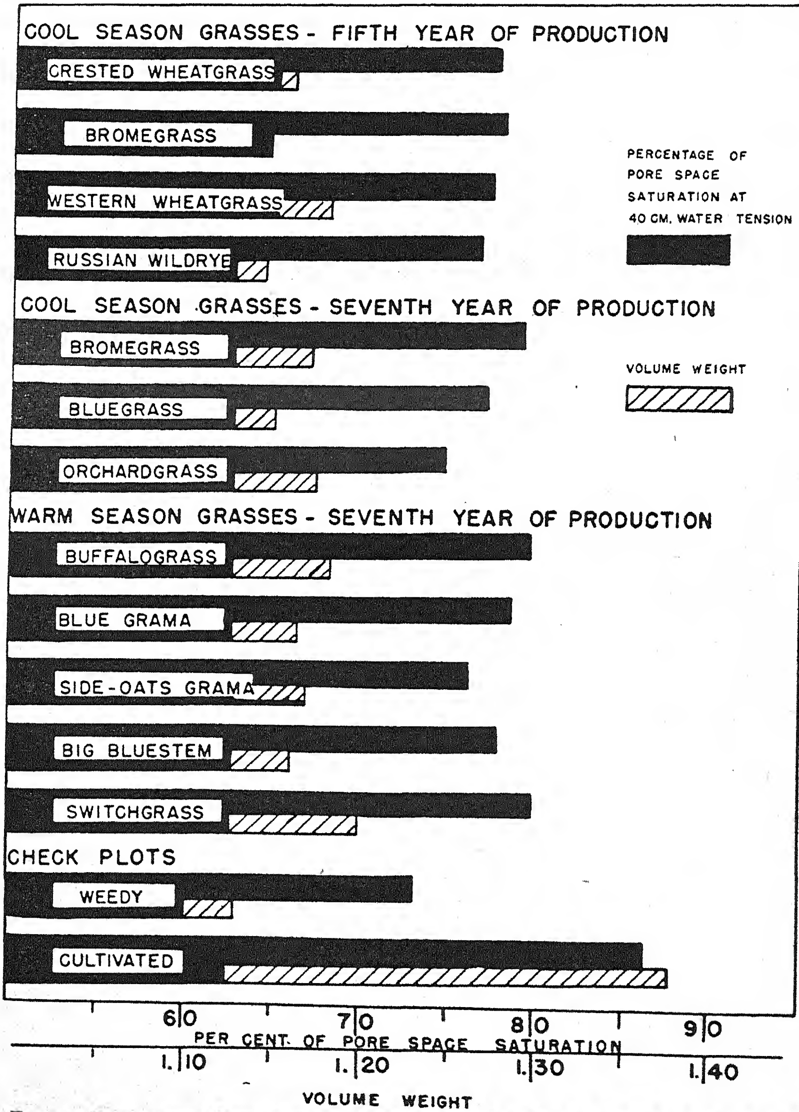

FIG. 4—Percentage of pore space saturation at a tension of 40 cm of water and the volume weight of the 1- to 3-inch depth of a Butler silty clay loam soil as influenced by various perennial grasses.

depth in each replication was used. The moisture curves obtained were typical curves (10), but no apparent differences were to be found among these grasses. This lack of differential in the shape of the curves might well be inferred from the similarity of the other data presented for the four grasses investigated.

TABLE 3.—*Effects of kind and age of grass cover on the percentage saturation of pore space at 40 cm of water tension.*

Kind and age of grass cover	Percentage of pore space saturation at 40 cm of water tension at		
	1–3 in.*	5–7 in.*	11–13 in.†
Grass Plots in Fifth Year of Production			
Cool-season grasses:			
Crested wheatgrass	77.7	79.3	85.5
Bromegrass	78.2	78.7	85.3
Western wheatgrass	77.3	82.1	78.4
Russian wildrye	76.6	81.0	84.2
Grass Plots in Seventh Year of Production			
Cool-season grasses:			
Bromegrass	79.2	80.0	81.6
Bluegrass	77.0	78.3	78.8
Orchard grass	74.8	76.1	74.1
Warm-season grasses:			
Buffalo grass	79.5	80.2	82.8
Blue grama	78.4	75.7	86.9
Side-oats grama	76.3	80.1	84.8
Big bluestem	78.0	86.5	86.5
Switchgrass	79.7	78.9	79.0
Check Plots			
Weedy plot	73.2	80.9	82.6
Cultivated field	86.4‡	79.6‡	75.3‡

*Average of eight plots.
†Average of two plots.
‡Comparison value only.

SUMMARY AND CONCLUSIONS

The effects of various perennial grasses on the chemical and physical properties of a fine-textured eastern Nebraska soil were investigated. Measurements of total nitrogen and readily oxidizable organic matter content were made as indicators of soil organic matter content. The percentage of soil aggregates greater than 0.25 mm, the percentage saturation of pore space at a tension of 40 cm of water, and the volume weight were physical measurements used to characterize the soil.

There was a highly significant difference in total nitrogen and readily oxidizable organic matter content of the soil under various grass covers for the 0 to 6-inch depth. The differences between grass covers were not significant for the readily oxidizable material at 6 to 12 inches. No distinct differences in total nitrogen content and readily

oxidizable material were observed in relation to seasonal growth habits of the several grasses. Blue grama, buffalo grass, bromegrass, blue grass, and orchard grass were grasses maintaining the highest organic matter content.

A highly significant difference in the percentage of soil aggregates greater than 0.25 mm diameter was obtained between soils under the various grasses for the 1- to 3-inch depth. The difference was significant at 5 to 7 inches and highly significant at 11 to 13 inches. Side-oats grama, blue grama, bluegrass, and bromegrass were grasses imparting the greatest stability to the soil aggregates.

No significant difference between sods was found for measurements of pore-space saturation or volume weight. It is thought that insufficient samples were taken to establish any relationships.

The regression coefficient for nitrogen content as related to the percentage of stable aggregates was significant at the 5% level. The regression coefficient for readily oxidizable material compared with aggregate stability was highly significant at the 1% level.

In all determinations, organic matter content and favorable physical conditions were maintained relatively higher under a grass cover than in an adjoining cultivated field. In comparison with a weedy check plot, the grass-covered plots were nearly all significantly higher in organic matter content.

Grasses apparently differ in their ability to stabilize soil aggregates. This stabilizing ability is correlated with total nitrogen content, or with readily oxidizable material. It is not closely related to the vegetative production of the various grasses. Seemingly it then must be a function of the differential root development of the individual perennial grasses.

The results obtained indicate that well-adapted perennial grasses in the cropping systems of fine-textured soils of eastern Nebraska will conserve the organic matter content and may provide increased structural stability to the soil granules. These factors are important items in the long range planning which will provide these soils with adequate protection against erosion and soil fertility depletion.

LITERATURE CITED

1. BAYER, L. D. Soil Physics. New York: John Wiley and Sons, Inc. 1940.
2. HIDE, J. C., and METZGER, W. H. Soil aggregation as affected by certain crops and organic materials and some chemical properties associated with aggregation. Soil Sci. Soc. Amer. Proc., 4:19–22. 1939.
3. JOACHIN, W. W. R., and KANDEAH, S. Soil fertility studies: 1. The effect of Napier grass fallow on soil composition and structure under Ceylon conditions. Trop. Agr. (Ceylon), 100:75–81. 1944. (Chem. Abs., 40:661. 1946.)
4. KURTESSOV, A. P. The effect of perennial grasses, maize, soya, and fallow on soil structure. Pedology, 8:77–81. 1939.
5. LEAMER, R. W., and SHAW, B. A simple apparatus for measuring non-capillary porosity on an extensive scale. Jour. Amer. Soc. Agron., 33:1003–1008. 1939.
6. MARTIN, W. S. Grass covers in their relation to soil structure. Emp. Jour. Exp. Agr., 12:21–32. 1944.
7. MCHENRY, J. R., and RUSSELL, M. B. Elementary mechanics of aggregation of puddled materials. Soil Sci. Soc. Amer. Proc. 8:71–78. 1943.
8. NEWELL, L. C., and KEIM, F. D. Effects of mowing frequency on the yield and protein content of several Nebraska grasses grown in pure stands. Nebr Agr. Exp. Sta. Res. Bul. 150. 1947.

9. RUSSELL, E. W. Soil structure. Imp. Bur. Soil Sci. Tech. Commun. 37. 1938.
10. RUSSELL, M. B. Pore-size distribution as a measure of soil structure. Soil Sci. Soc. Amer. Proc., 6:108–112. 1941.
11. SMITH, HENRY W., and WELDON, M. D. A comparison of some methods for the determination of soil organic matter. Soil Sci. Soc. Amer. Proc., 5:177–182. 1940.
12. SOKOLOVSKY, A. N. The problem of soil structure. Trans. Int. Soc. Soil Sci., Soviet Sect. A, 34–110. 1934.
13. VOROBIEVA, E. I. The role of perennial grasses in raising the yielding capacity of chestnut soils. Pedology, 11:81–88. 1939. (Soils and Fertilizers, 4:70. 1941.).

Stands and Methods of Planting for Corn Hybrids[1]

G. H. Stringfield and L. E. Thatcher[2]

In some of the earlier Ohio experiments comparing corn hybrids with open-pollinated varieties, the writers observed that adapted hybrids generally had a lower incidence of barrenness or near-barrenness than did the open-pollinated varieties. This observation led to the hypothesis that the hybrids should have the higher optimum stands. If they did have, it would be necessary to revise recommendations for planting rates where hybrids were grown. The stand problem had been reasonably well solved for open-pollinated varieties, but it seemed desirable to extend the work using hybrids.

REVIEW OF LITERATURE

Roberts and Kinney (6),[3] after experimenting with open-pollinated corn at varying rates, both hilled and drilled, and under varying conditions of plant growth, reached the following conclusions: "To summarize, it would seem that on rich soil in a normal season relatively thick planting will give the highest yields. In dry seasons, thin planting gives the best results. On poor land best yields will be secured from rather thin planting. Planting more than 3 stalks to the hill may result in a higher yield, but the corn is likely to fall badly and the quality of the corn will not be as good... Large varieties of corn are not as well adapted to thick planting as small varieties. The cost of harvesting the corn when planted thick is greater. Finally it may be said that on good corn land of fair fertility 3 stalks per hill or the equivalent in drilled corn will probably give the best results when the average of a number of years is considered."

After extensive testing of southern open-pollinated varieties under varying conditions of soil and season, Mooers (4) established a simple formula for estimating optimum stands. Variables in the formula are the estimated grain yield for the field, and a factor which varies with the productivity of the field. The latter is the weight of grain per plant, which was indicated by the experiments to accompany an optimum stand at a given acre-grain yield.

Richey (5) has summarized the results of many experiments in the South and in the Corn Belt published prior to 1933. These experiments led to the conclusions that the optimum stand for corn is heavier as one proceeds from larger to smaller plants, from the South northward, from low to high moisture supply, and from low to high soil productivity.

Kiesselbach, *et al.* (2), after comparisons extending over 12 years, concluded that an average of 2½ to 3 plants in checkrowed hills 42 inches apart, or the equivalent in drilled rows, was most practical for standard open-pollinated varieties in eastern Nebraska. They found that there could be some variation in planting rate without materially affecting yields under their conditions.

Samarina (7), working at Saratov, U.S.S.R., which is comparable to southern Canada in latitude, found the most desirable rate for local varieties to be 2,450 square centimeters per plant. This would correspond to 16,518 plants per acre, or 4.64 plants per hill at 42-inch spacing. This paper was read by abstract only.

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[1]Contribution from the Agronomy Department, Ohio Agricultural Experiment Station, Wooster, Ohio, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Journal Article No. 20–47, Ohio Agricultural Experiment Station. Received for publication July 18, 1947.

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[3]Figures in parenthesis refer to "Literature Cited", p. 1010.

Innes (1), working in Jamaica, probably with open-pollinated corn, obtained acre-grain yields of 32.0, 40.0, and 43.0 bushels from planting rates which gave final stands corresponding to 2.43, 3.07, and 4.07 plants per hill at 42-inch spacing. With increasing rates of planting he found no difference in plant height, or in the percentage of plants destroyed by smut infection, a decrease in the ratio of plants to seeds planted, in the incidence of plants with two or more ears, and in the weight of grain per plant.

METHODS

Since the experiments were conducted over a long period of years, the experimental methods were not uniform throughout. Part of the description of methods will have to be given specifically for the separate phases of the investigation.

In all cases where yields per acre are reported they are in terms of shelled grain carrying 15½% of moisture. Prior to 1935, the total plot ear weight was taken and a 50-pound moisture sample of ears from each plot was placed in dry storage for several months. Weights were then taken before and after shelling and the moisture content of the grain was determined with the Brown-Duvel apparatus. The ratio of shelled grain to the original ear weight of the sample was then applied to the original ear weight of the plot to compute the plot yield.

In 1935 and 1936 the same general method was followed, but since the plots were smaller the moisture sample was taken from only 12 to 15 plants systematically chosen from each plot.

After 1936 the moisture sample for a plot consisted of two kernel rows shelled from each ear and nubbin from 12 or more systematically chosen plants. A table prepared by the Iowa Agricultural Experiment Station showing the relation between moisture content of grain and the weight of ears required to make a bushel of shelled grain at 15½% moisture was used as a basis for computing the acre-grain yields.

The silking date is a determination of the median date based on actual counts. The plots were inspected on alternate days during the silking period. When it could be seen from observation that about one-third or more of the plants in a plot were in silk, a count was made. The following corrections suggested by Meyers (3) were added to or subtracted from the date on which the stated percentages of plants were observed in silk to estimate the date when half the plants were in silk:

Add or subtract from	When the percentage of plants is	
The date of record	Below	Above
1 day	42	58
2 days	29	71
3 days	19	81

A plant was counted as root lodged when, through failure of the roots to hold it erect, it leaned more than about 30 degrees.

A plant was counted as broken only when the stalk was broken below the ear-bearing node.

GRAPHIC PRESENTATION

Though some of the experiments were in 40-inch rather than 42-inch rows, the points of intersection in all the graphs were based upon plants per acre rather than plants per hill, and the upright guide lines all indicate stands comparable with checkrowed hills spaced 42 inches each way. All the curves are freehand.

EXPERIMENTAL RESULTS

COMPARISONS WITHIN THE OPEN-POLLINATED VARIETY CLARAGE

An experiment comparing differences in stands of open-pollinated Clarage corn was begun at Wooster by Williams and Welton (8) in 1904 and continued through a 21-year period. The stands were one to five plants per hill, inclusive, in checkrowed hills spaced 42 inches

each way. The plots were 1/10 acre in size without replication. Heavier rates were planted with subsequent thinning to obtain the stands desired.

The results are shown graphically in Fig. 1.

Fig. 1 shows clearly that the effect of stand on yield was greater in good seasons than in poor, and that comparing four plants with three, the loss was less at a yield potential of just under 50 bushels than was the gain at a yield potential of over 75 bushels. Some additional data on this experiment are given in Table 1.

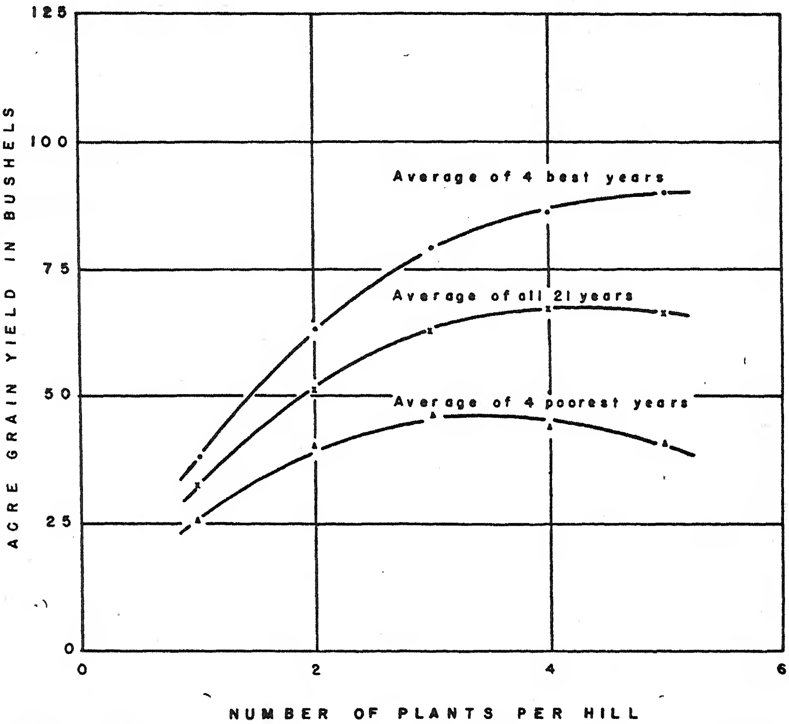

FIG. 1.—Grain yields of Clarage open-pollinated corn with one to five plants per hill. Wooster, Ohio, 1904 to 1924.

Ear weights ranging roughly between 0.45 and 0.55 pound were found at optimum stands, with the lower values appearing at yield potentials of just under 50 bushels and the higher values at yield potentials of over 75 bushels. This relationship is of the same type and not greatly different in magnitude from that reported by Mooers (4).

HYBRIDS COMPARED WITH OPEN-POLLINATED VARIETIES

In 1936, 60 hybrid entries and 6 open-pollinated varieties were compared in six replications of 2- by 10-hill plots in randomized blocks. Two replications were thinned to a uniform stand of two

TABLE 1.—*Air-dry ear weights per plant and other data from a rate of stand experiment with Clarage open-pollinated corn, Wooster, Ohio, 1904 to 1924, inclusive.*

	Plants per hill, 42-inch checkrows				
	1	2	3	4	5
Air-dry Weight of Ears per Plant, Lbs.					
Av., 4 years of lowest yields	0.65	0.51	0.46	0.39	0.38
Av., 4 years of highest yields	0.68	0.71	0.65	0.56	0.51
Av., all 21 years	0.65	0.63	0.55	0.46	0.41
Proportion of the Plants, 21-year av., %					
Bearing ears	79.4	76.9	69.6	56.9	44.3
Bearing nubbins	13.5	12.9	15.7	22.7	28.6
Barren	7.1	10.2	14.7	20.4	27.1
Bearing 2 ears	17.2	5.6	3.1	1.7	1.3

plants per hill, two were thinned to three plants per hill, and two were thinned to four plants per hill. The hybrids had an average of 1.7% more moisture in the ears at harvest, but this small difference in indicated average maturity would not account for the different

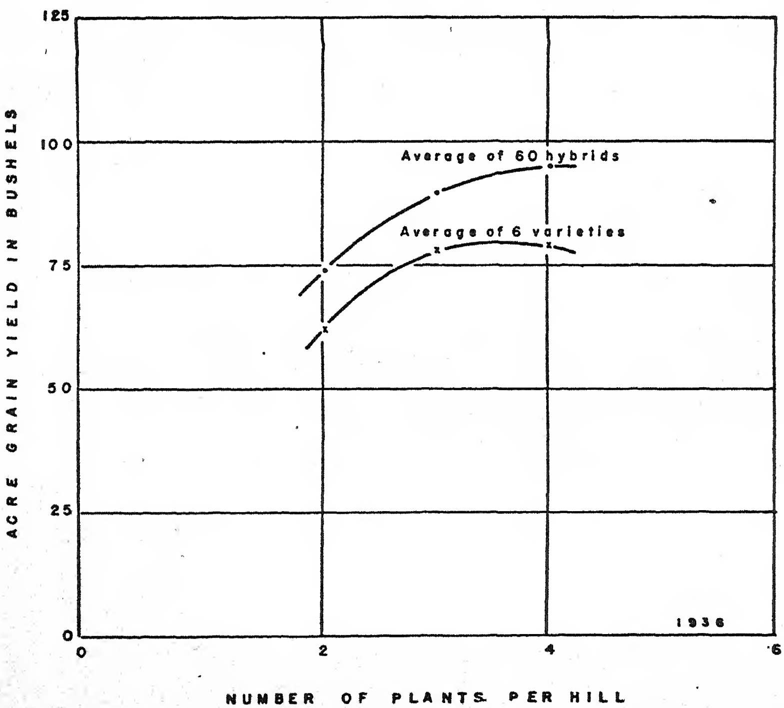

FIG. 2.—Grain yields of 60 hybrids and six open-pollinated varieties at each of three rates of stand. Wooster, Ohio, 1936.

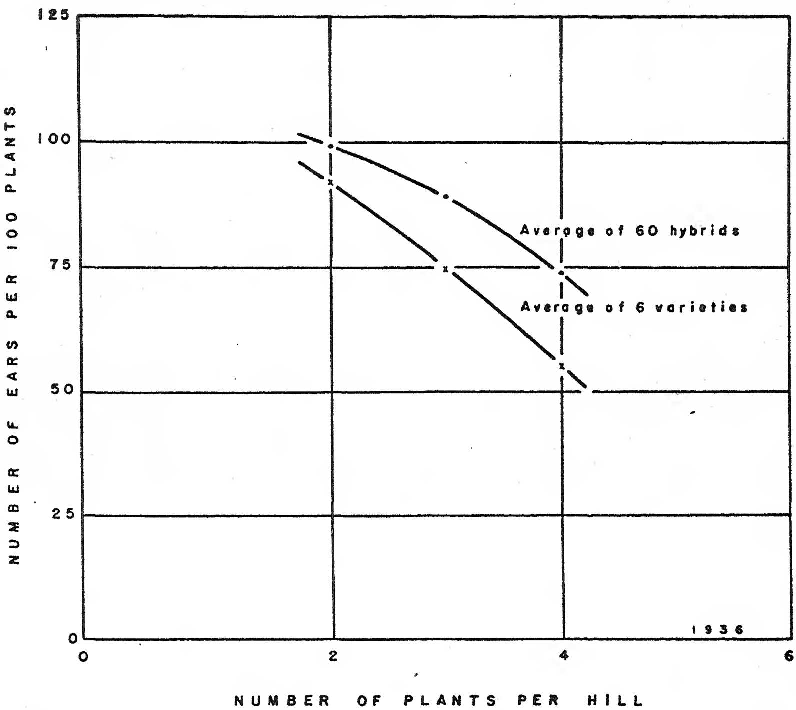

FIG. 3.—Average number of ears per 100 plants at three different stands of 60 hybrids and six open-pollinated varieties. Wooster, Ohio, 1936.

response to spacing shown in Figs. 2 and 3. The optimum stand for the hybrids was higher by perhaps half a plant per hill. The incidence of barrenness was uniformly lower in the hybrids, and the increase in barrenness due to thicker stands was less in the hybrids than in the open-pollinated varieties. A similar experiment in 1935 with 33 hybrids and 13 open-pollinated varieties at two rates of stand confirms these results. In that experiment the hybrids averaged no later than the varieties.

RATE OF STAND AND METHOD OF PLANTING HYBRIDS OF DIFFERENT SEASONAL REQUIREMENTS

In 1941 the hybrids Ohio M15, Ohio W17, and Ohio C98, early, midseason, and full-season, respectively, were compared at five rates of stand in both checkrowed hills and drilled rows. Replication was fivefold in randomized blocks. The harvested plots were three rows wide and approximately 320 inches long, depending on the type of planting. Buffer rows planted at the sides and buffer hills or plants at the ends were not harvested. The plot length was considered as the distance between the end hills or end plants plus half the distance to the next hill or plant at each end.

The corn followed alfalfa on a productive field. Before planting, a 2-12-6 fertilizer was drilled in the rows at the rate of 125 pounds per acre. The plots were not thinned. Actual stand counts were taken.

TABLE 2.—*Data from an early, a midseason, and a full-season hybrid planted at five rates in checkrowed hills and in drilled rows, Wooster, Ohio, 1941.*

Hybrid	Method of planting	Number of seeds per 40-inch space					Average
		2	3	4	5	6	
		Acre Yields of Grain, Bushels					
Ohio M15 (early)	Hill	72.1	87.2	94.8	108.5	103.9	93.3
	Drill	59.2	91.4	110.3	101.8	98.7	92.3
Ohio W17 (midseason)	Hill	78.9	86.9	94.5	85.9	74.5	84.1
	Drill	78.8	77.4	86.1	93.7	75.0	82.2
Ohio C98 (full-season)	Hill	88.9	105.7	123.3	98.6	122.1	107.7
	Drill	73.0	103.4	107.4	125.9	119.5	105.8
Average		75.2	92.0	102.7	102.4	99.0	—
		Percentage of Perfect Stand					
Ohio M15	Hill	93.4	84.5	84.6	80.9	78.8	84.4
	Drill	70.1	82.3	88.9	93.9	83.0	83.6
Ohio W17	Hill	98.8	90.9	85.7	82.4	88.4	89.2
	.Drill	84.2	91.4	90.6	93.5	86.0	89.1
Ohio C98	Hill	82.9	78.1	83.6	77.9	77.4	80.0
	Drill	74.5	83.1	80.7	87.2	79.6	81.0
Average		84.0	85.1	85.7	86.0	82.2	—
		Root-lodged Plants, %					
Ohio M15	Hill	0.4	0.7	1.0	2.9	1.9	1.4
	Drill	5.3	4.4	8.2	4.8	15.9	7.7
Ohio W17	Hill	1.3	3.4	1.2	0.4	1.9	1.6
	Drill	3.3	3.6	4.0	5.7	8.1	4.9
Ohio C98	Hill	3.2	0.0	2.9	1.3	3.6	2.3
	Drill	5.3	24.0	2.1	5.5	7.1	8.8
Average		3.1	6.0	3.2	3.4	6.4	
		Plants Broken Below Ear, %					
Ohio M15	Hill	12.0	19.1	41.9	29.5	43.5	31.2
	Drill	10.1	20.6	33.0	48.7	40.4	30.6
Ohio W17	Hill	7.2	18.7	37.5	31.2	32.6	25.4
	Drill	13.5	18.8	26.4	44.2	39.7	28.5
Ohio C98	Hill	26.6	20.7	42.4	44.9	59.0	38.7
	Drill	32.6	33.1	27.8	43.0	51.6	37.8
Average		17.0	21.8	34.8	40.3	44.5	—

TABLE 2.—*Concluded.*

Hybrid	Method of planting	Number of seeds per 40-inch space					Average
		2	3	4	5	6	
		Height of Ear Node, Inches					
Ohio M15	Hill	40.9	45.2	45.9	47.0	46.9	45.2
	Drill	42.0	43.6	47.2	47.7	48.1	45.7
Ohio W17	Hill	39.6	41.2	43.4	43.7	45.8	42.7
	Drill	42.0	43.1	43.8	46.8	45.2	44.2
Ohio C98	Hill	49.3	50.9	55.7	54.0	56.2	53.2
	Drill	48.3	52.9	54.5	55.3	55.9	53.4
Average........		43.7	46.2	48.4	49.1	49.7	—
		Tillers per 100 Plants, Number					
Ohio M15	Hill	18.7	7.2	3.7	3.5	6.5	7.9
	Drill	43.6	14.9	7.5	3.2	3.3	14.7
Ohio W17	Hill	50.6	17.5	9.5	7.7	5.2	18.1
	Drill	114.0	85.4	65.8	32.6	20.7	63.7
Ohio C98	Hill	21.1	8.5	6.5	5.7	8.1	10.0
	Drill	39.5	43.2	23.1	14.2	12.2	26.4
Average........		47.9	29.4	19.4	11.2	9.3	—

Since there was no significant difference in yield between the check-rowed and the drilled plots even at the heavy stands, the yields from the two methods of planting are combined in Fig. 4.

Unfortunately, an inferior lot of seed of the midseason hybrid, Ohio W17, was planted and its performance was not typical. The yields of Ohio C98, although disappointingly irregular, suggest that this full-season hybrid has a higher optimum stand than does the early hybrid. The difference, however, appears to have been no greater than would be expected on the basis of the difference in average yield between the two.

Data on several agronomic characters are shown in Table 2. In 14 of the 15 comparisons, the drilled plots lodged more than did the hilled plots. That difference did not hold, however, in stalk breakage, but stalk breakage consistently increased with rate of stand. Ear height was not affected by method of planting, but it increased with heavier stands.

Tillering ranged from heavy in the thin stands to light in the thick stands, and the drilled plots had more than twice as many tillers as did the hilled plots. Any nubbins or ears that appeared on tillers were harvested and weighed in with the plots. Since the yields were about the same from drilled and hilled plots, it would appear that the additional tillers were of no advantage.

RATE OF STAND AND METHOD OF PLANTING ON FOUR LEVELS OF SOIL PRODUCTIVITY

In 1942 an experiment was started to study the relation between the level of soil productivity and the optimum stand of a good hybrid. Four levels of soil productivity had been established on Canfield silt loam by the treatments shown in Table 3. The entire plot area was limed to attain a soil reaction of approximately pH 6.5.

Ohio Hybrid K24 was planted, both in hills and drills, at three, four, five, and six seeds per 40-inch space in rows 40 inches apart. The plots were 6 hills wide by 10 hills long in fourfold replication in four

TABLE 3.—*Manure and fertilizer applications per acre used in the establishment of four levels of soil productivity on Canfield silt loam, Wooster, Ohio.*

Productivity level	Corn		Oats or soybeans	Wheat	
	0–16–0, lbs.	Manure, tons		Fall, 2–14–4, lbs.	Spring, am. sulfate, lbs.
A	0	0	0	0	0
B	200	4	0	200	40
C	400	8	0	400	80
D	800	16	0	800	160

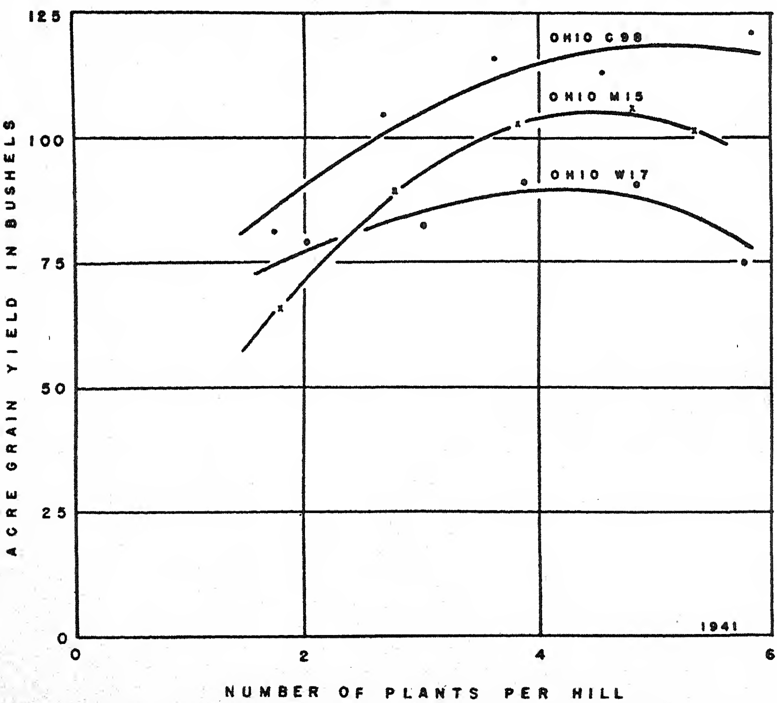

FIG. 4.—Grain yields at varying rates of stand of three hybrids, Ohio M15, early; Ohio W17, midseason; and Ohio C98, full-season. Wooster, Ohio 1941.

randomized blocks at each productivity level. Half of each plot was planted in checkrowed hills and the other half was planted in drilled rows with equivalent stands. The split-plot design was used because space was limited and there was good reason to believe from the previous years' work that there would be no measurable difference in the competition of hilled and of drilled rows having the same stands. The outer rows on each side of the plots were discarded. Discards from the ends of the plots were the same as described for the 1941 experiment.

The experiment was continued with minor modifications in 1943. The same rotation field was used but another rate was added and Ohio M15, an earlier hybrid, was used because a wet May necessitated late (June 8) planting. The plots were 4- by 10-hills with two unrestricted randomized blocks at each productivity level. The field was cultivated only twice. However, the weeds were pulled out of the rows of the highest productivity level before the second cultivation. Only that level tended to be weedy.

The grain yields from the 1942 and 1943 experiments, summarized without reference to method of planting, are shown graphically in Figs. 5 and 6. The small response to rate of stand in 1942 may be the

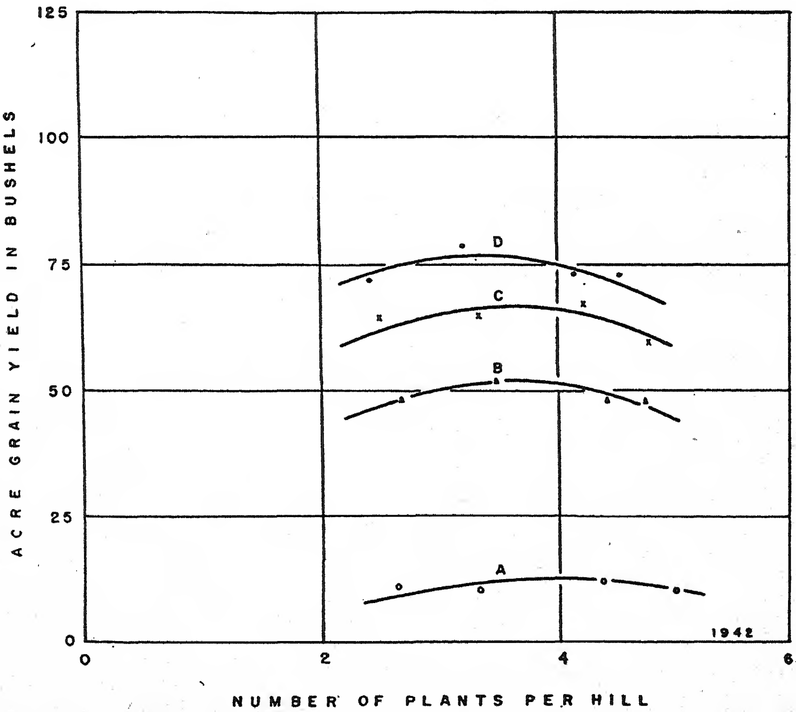

FIG. 5.—Grain yields at varying rates of stand as obtained from the hybrid Ohio K24 on each of four levels of soil productivity in a dry season. Wooster, Ohio, 1942.

result of deficient soil moisture during most of July and August. The yields were low and all of the grain was poorly filled.

There was not enough lodging or tillering in 1942 to give any information. Percentage of a perfect stand was virtually constant at about 76 to 78 for the planting rates of three, four, and five plants per 40-inch hill space, then dropped slightly to 72 at the rate of six plants.

TABLE 4.—*Data from Ohio M15 hybrid planted at five rates and by two methods on four levels of soil productivity, Wooster, Ohio, 1943.*

Productivity level	Method of planting	Number of seeds per 42-inch space					Average
		2	3	4	5	6	
		Acre Yields of Grain, Bushels					
A	Hill	27.0	28.9	29.9	29.1	27.7	28.5
	Drill	32.8	27.7	27.7	34.6	37.6	32.0
B	Hill	57.5	75.8	88.0	92.4	85.9	79.9
	Drill	53.0	76.2	88.3	84.7	82.3	76.9
C	Hill	69.0	86.1	96.1	101.7	104.4	91.5
	Drill	61.9	83.4	101.6	100.6	107.6	91.0
D	Hill	69.7	89.2	99.6	107.5	105.2	94.2
	Drill	74.7	88.5	102.5	106.4	110.1	96.4
Average		55.7	69.5	79.2	82.1	82.6	—
		Percentage of Perfect Stand					
A	Hill	84.4	75.7	85.5	91.7	88.2	85.1
	Drill	92.3	77.8	78.5	85.8	87.6	84.4
B	Hill	87.5	89.6	95.3	91.7	92.4	91.3
	Drill	92.2	86.2	90.3	86.7	89.7	89.0
C	Hill	96.9	93.8	89.6	91.7	93.4	93.1
	Drill	93.3	92.4	95.2	83.0	89.5	90.7
D	Hill	97.9	95.8	96.9	93.8	93.1	95.5
	Drill	103.3	94.5	90.9	83.0	80.2	90.4
Average		93.5	88.5	90.3	88.4	89.3	—
		Days from Planting to Silking					
A	Hill	72.5	72.5	76.5	77.0	73.0	74.3
	Drill	70.5	77.0	77.0	76.0	75.0	75.1
B	Hill	64.0	64.0	64.5	65.5	67.0	65.0
	Drill	65.5	63.5	65.5	65.0	66.0	65.1
C	Hill	61.0	61.0	62.0	63.5	63.5	62.2
	Drill	58.0	61.0	60.5	60.0	61.5	60.2
D	Hill	59.5	59.0	61.5	61.5	62.0	60.1
	Drill	59.5	59.0	60.0	60.0	60.0	59.7
Average		63.8	64.6	65.9	66.1	66.0	—

TABLE 4.—*Concluded.*

Productivity level	Method of planting	Number of seeds per 42-inch space: 2	3	4	5	6	Average
		Average Field Weight of Ears, Pounds					
A	Hill	0.40	0.33	0.25	0.22	0.18	0.28
	Drill	0.46	0.34	0.27	0.24	0.21	0.30
B	Hill	0.73	0.70	0.60	0.51	0.42	0.59
	Drill	0.66	0.70	0.63	0.50	0.42	0.58
C	Hill	0.79	0.72	0.64	0.56	0.51	0.64
	Drill	0.70	0.68	0.66	0.60	0.52	0.63
D	Hill	0.67	0.70	0.62	0.58	0.49	0.61
	Drill	0.65	0.69	0.68	0.64	0.58	0.65
Average		0.63	0.61	0.54	0.48	0.42	—
		Ears per Plant, Number					
A	Hill	1.08	1.02	0.96	0.78	0.80	0.93
	Drill	1.00	0.94	0.92	0.92	0.93	0.94
B	Hill	1.12	1.04	0.96	0.98	0.96	1.01
	Drill	1.12	1.07	0.99	0.99	0.95	1.02
C	Hill	1.16	1.05	1.05	0.99	0.94	1.04
	Drill	1.17	1.09	1.00	1.00	0.93	1.04
D	Hill	1.32	1.11	1.04	0.98	0.97	1.08
	Drill	1.35	1.12	1.03	0.99	0.98	1.09
Average		1.17	1.06	0.99	0.95	0.93	—
		Bushel Test Weight, Pounds					
C	Hill	59.9	59.0	59.8	59.8	59.5	59.6
	Drill	59.5	59.8	59.5	59.5	59.6	59.6
D	Hill	59.5	59.5	59.2	58.9	59.5	59.3
	Drill	59.2	59.3	59.0	59.2	59.3	59.2
Average		59.5	59.4	59.4	59.5	59.5	—
		Average Kernel Rows per Ear, Number					
C	Hill	17.2	17.1	17.0	17.2	17.3	17.2
	Drill	17.2	17.2	17.1	17.2	17.2	17.2
D	Hill	17.2	17.6	17.0	17.1	17.0	17.2
	Drill	17.3	17.3	17.2	17.2	17.2	17.3
Average		17.2	17.3	17.1	17.2	17.2	—
		Green Weeds per Acre, Tons					
D	Hill	2.63	1.88	1.06	0.79	0.42	1.36
	Drill	2.50	1.17	0.50	0.52	0.34	1.01
Average		2.57	1.53	0.78	0.66	0.38	—

The average number of days from planting to mid-silking in 1942 at the four rates of stand from thin to thick were, 79.0 79.8, 80.7, and 81.5, respectively.

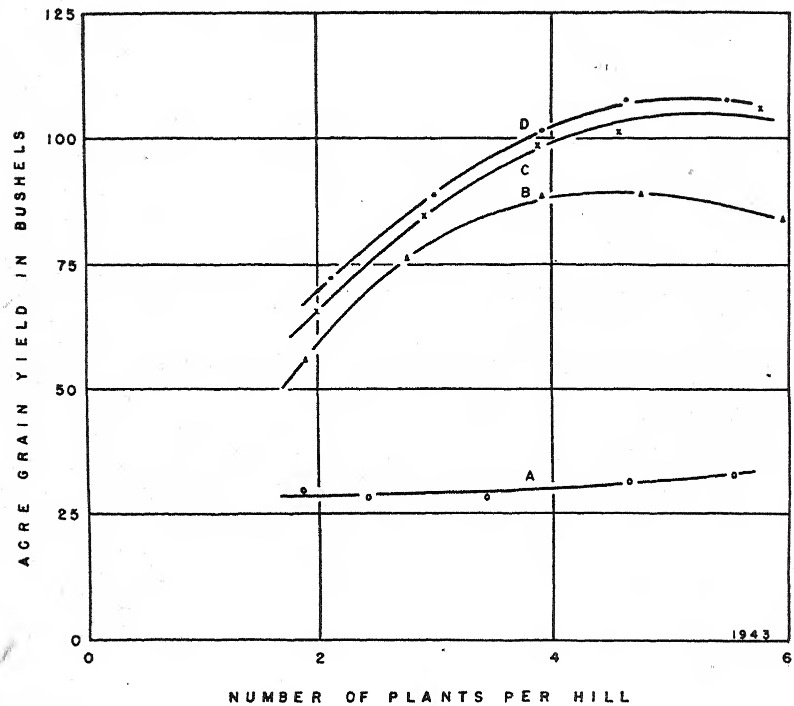

FIG. 6.—Grain yields at varying rates of stand as obtained from the hybrid Ohio M15 on each of four levels of soil productivity in a favorable season. Wooster, Ohio, 1943.

The data from the 1943 experiment are presented in detail in Table 4. Contrary to earlier results there was no drop in percentage of perfect stand at the heaviest planting rate. The previously noted delay in maturity as measured by mid-silking date was found only in the range from the two-seed to the four-seed planting rate. With the late planting, June 8, the period from planting to silking was greatly reduced and marked differences would not be expected.

The average weight of ears was affected markedly by both soil productivity and rate of stand. Where the stand was heavy enough to take full advantage of soil productivity, the ears averaged less than 0.7 pound as they came from the plants, and there was only one ear per plant. There was practically no tillering in the planting. The test weight per bushel and the number of kernel rows per ear remained constant at all rates of stand.

The only plots that could be called weedy were those of the thin-stand rates on the D productivity level. Weeds were harvested by

clipping close to the ground in early September and were then weighed green.

METHOD OF PLANTING

Both checkrowed hills and drilled rows were included in the study of rates of stand because of the possibility that the two methods of planting might show different optimum rates at comparable levels of soil productivity. The 1941 experiment had a significantly higher incidence of root lodging in the drilled rows than in the checkrowed hills. It would seem unsafe, however, to generalize from this one experiment. The whole experiment averaged only 4.6% of root-lodged plants.

The stand in terms of percentage of seed planted was the same for the two methods of planting in 1941; it was higher in the drilled rows by 3% of the seeds planted in 1942; and it was significantly higher in the checkrowed hills by 3% of the seeds planted in 1943. No generalizations seem warranted here.

As between the two planting methods, grain yields were not significantly different at any rate of stand or in any season (Fig. 7).

SIGNIFICANCE OF DIFFERENCES IN YIELD

The graphs, except for the 1942 experiment, show a tendency for a wider spread in yield as the stands increase. The 1942 crop was badly

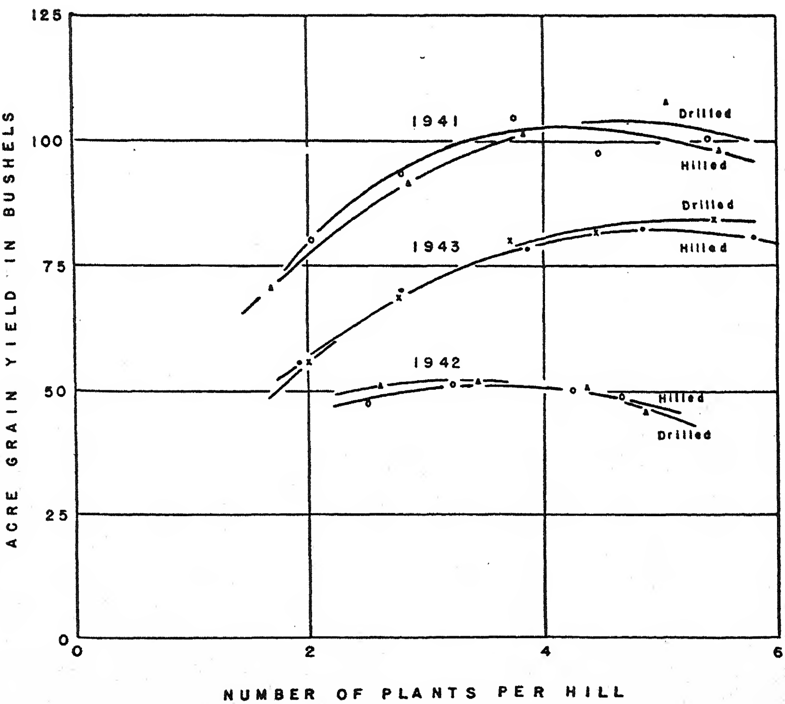

FIG. 7.—A graphic summarization of grain yields arranged to compare hilled with drilled corn at varying rates of stand. Wooster, Ohio, 1941 to 1943.

injured by drouth during the grain-filling period. Thus, in the absence of drought, the heavier stands influence the grain yields in increasing magnitude as growth conditions become more favorable. Another experiment, in addition to those reported here, showed this relationship also. The odds that this degree of agreement appeared through random sampling are too remote for consideration. This statement is made despite the fact that the analysis of variance did not show statistical significance for the rate times hybrid interaction in 1941, or for the rate times productivity-level interaction in 1942 or 1943.

Productivity level A was not included in the 1942 or in the 1943 analysis. Least significant differences between points in the graphs are: Fig. 2, 4.3 bushels; Fig. 4, 13.8 bushels; Fig. 5, productivity level A, 5.0 bushels; Fig. 5, productivity levels B, C, and D, 5.22 bushels; Fig. 6, productivity level A, 5.7 bushels; Fig. 6, productivity levels B, C, and D, 8.6 bushels.

SUMMARY AND CONCLUSIONS

Experiments at the Ohio Agricultural Experiment Station are reported, comparing corn planted at different rates, in hills and drills, and on soils of four different productivity levels. The results support the findings of other workers in indicating that as growing conditions become more favorable the optimum stands are higher. They also show that adapted hybrids as a group have higher optimum stands than do open-pollinated varieties of comparable seasonal requirement, probably because of the greater vigor of the hybrids. The difference between the two optima amounts to about 1,800 to 2,000 plants per acre under favorable growing conditions.

The effect of stand on grain yields is much greater at high than at low productivity levels. It would follow that where different soil treatments are being studied in field experiments, the planting rate should be the one expected to give an optimum stand for the better treatments. Such a stand would affect the poorer treatments relatively little but would make it possible to measure the full productivity of the better treatments.

At optimum stands, the air-dry ears averaged a little more than half a pound each. The great pound-sized ears so often displayed in corn exhibits and sales literature merely indicate inefficient use of a favorable environment for corn. Furthermore, at optimum stands, competition tended to throw some of the plants into near or complete barrenness. Thirty-three hybrids averaged 113.7 bushels per acre with 13% barren or near-barren plants in 1935; and at the rate considered optimum, 60 hybrids averaged 89.1 bushels with 11% barren or near-barren plants in 1936.

Tillering decreased rapidly as stands approached the optimum. At comparable stands tillering was much heavier in drilled rows than in checkrowed hills. In 1941 (Table 2) the much higher incidence of tillering in the thinner drilled rows was not accompanied by higher yields than in the checkrowed hills of comparable stands.

The experiments revealed no consistent relation between rate of planting and resultant stand in terms of percentage of seed planted.

Weeds were much more abundant where stands were thin in an experiment in 1943.

The test weight of grain did not appear to be affected by differences in stand.

There are several unfavorable effects of the heavier stands (Table 5). The harvested crop is less attractive because of the smaller ears and the higher proportion of nubbins. The silking period for a stand of five plants per 42 inches of row-space was roughly 2 days later than for a stand of three plants in the same space. This would probably delay maturity by four or five days. Conceivably the less abundant mineral nutrient supply for the individual plants could affect the feeding quality of the grain adversely. The most serious effect of the heavier stands is in the higher incidence of stalk breakage.

TABLE 5.—*Summary of the data on plant characters in relation to planting rate, Wooster, Ohio.*

Year	Number of seeds per hill or hill-space				
	2	3	4	5	6
	Stand in Percentage of Seeds Planted				
1941	84.0	85.1	85.7	86.0	82.2
1942	—	77.3	75.7	78.0	72.1
1943	93.5	88.5	90.3	88.4	89.3
	Days from Planting to Silking				
1942	—	79.0	79.8	80.7	81.5
1943	63.8	64.6	65.9	66.1	66.0
	Root-lodged Plants, %				
1941	3.1	6.0	3.2	3.4	6.4
1942	—	3.0	4.0	3.3	2.2
	Plants Broken Below Ear Node, %				
1941	17.0	21.8	34.8	40.3	44.5
1942	—	1.9	2.0	1.8	2.1
	Height of Ear Node, Inches				
1941	43.7	46.2	48.4	49.1	49.7
	Tillers per 100 Plants, Number				
1941	47.9	29.4	19.4	11.2	9.3
	Average Ear Weight at Harvest, Pounds				
1943	0.63	0.61	0.54	0.48	0.42
	Ears per 100 Plants, Number				
1943	117	106	99	95	93
	Test Weight of Bin-dried Grain, Pounds*				
1943	59.5	59.4	59.4	59.5	59.5
	Green Weeds per Acre, Tons†				
1943	2.57	1.53	0.78	0.66	0.38

*Levels C and D only.
†Level D only.

For the reasons just given, the writers would set the optimum stand lower than the one that gives maximum yields. On highly productive fields, one might reasonably sacrifice five bushels per acre in yield in order to gain a higher proportion of well-filled ears and a lessened hazard of soft corn and of stalk breakage from somewhat thinner stands. With these considerations in mind, and assuming that rates of stand will be 15 to 20% lower than rates of planting, the following recommendations have been given to Ohio farmers:

1. Estimate the yielding capacity of the field in question for a reasonably good season. If this estimate is 60 bushels or less of grain per acre, plant three viable seeds per hill or per 42 inches of row-space. For higher estimated yields plant the number obtained by dividing the estimated yield by 20. A divisor of 25 is suggested for the later, larger hybrids in southern Ohio.

2. Where it is desirable to establish seedings of ryegrass or other small-seeded plants directly in growing corn, the stand will need to be lower and some reduction in immediate corn yield should be conceded. Such seedings are affected by the stand of corn in the same way as are weeds.

3. There is no indication that the acre-stand should be any different in drilled rows than in checkrowed hills.

LITERATURE CITED

1. INNES, R. F. The spacing of maize on Jamaica "red dirt" (Terra Rossa soils). Jour. Jamaica Agr. Soc., 45:130–137. 1941.
2. KIESSELBACH, T. A., ANDERSON, A., and LYNESS, W. E. Tillage practices in relation to corn production. Neb. Agr. Exp. Sta. Bul. 232:10–11. 1928.
3. MEYERS, M. T. Determining date of silking in experiments with corn. Jour. Amer. Soc. Agron., 22:280–283. 1930.
4. MOOERS, C. A. Planting rates and spacing for corn under southern conditions. Jour. Amer. Soc. Agron., 12:1–22. 1920.
5. RICHEY, F. D. Corn culture. U. S.D.A. Farmer's Bul. 1714:18–20. 1933.
6. ROBERTS, GEORGE, and KINNEY, E. J. Corn production. Ky. Agr. Exp. Sta. Bul. 163:189–191. 1912.
7. SAMARINA, V. I. Experiments with corn. (Abstract) Saratov Agr. Exp. Sta. Short Rpts., Saratov, U. S.S.R., 1925/1926:55–60. 1927.
8. WILLIAMS, C. G., and WELTON, F. A. Corn experiments. Ohio Agr. Exp. Sta. Bul. 282:80–82. 1915.

The Genome Approach in Radical Wheat Breeding[1]

E. S. McFadden and E. R. Sears[2]

THE rediscovery of Mendel's laws at the beginning of the present century soon created interest in the possibility of transferring desirable characters from other species and genera to common wheat, *Triticum vulgare* Vill. Carleton (3)[3] suggested as early as 1901 that rust resistance and certain other characters could perhaps be transferred from the tetraploid wheats (emmers and durums) to common wheat. A few years later, McFadden (17) suggested the possibility of obtaining greater winterhardiness from rye, *Secale cereale* L. Still later, in a series of papers which were never widely publicized, McFadden (18, 19, 21)[4] briefly reported on his crossbreeding experiments involving the *Agropyrons* dating back to 1914, and called attention to numerous characters in the genus *Agropyron* that would be of value in the cultivated wheats. Among the *Agropyron* characters specifically mentioned were perennial nature, resistance to heat and drought, extreme winterhardiness, resistance to frost, resistance to alkaline and acid soil conditions, resistance to various diseases, and wide geographic adaptation of the various species. In another paper, McFadden (20) advocated a thorough study of the whole subject of interspecific and intergeneric hybridization with respect to wheat improvement, and more recently discussed (22) the possibilities of obtaining desirable characters from the various species of *Aegilops*.

In the four and a half decades since the first highly speculative suggestions on the use of wide crosses in wheat breeding, many investigations have been conducted in this field and much of value has resulted. Not only have new wheat materials of great practical worth been accumulated, but fundamental knowledge of the wheat group and its relatives has been greatly extended in the fields of taxonomy, cytology, genetics, and phylogeny.

REVIEW OF LITERATURE

FUNDAMENTAL STUDIES

Sakamura (35) found that the three taxonomic groups of wheats—the einkorns,

[1]Investigations conducted by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Texas Agricultural Experiment Station, College Station, Texas, and the Field Crops Department, Missouri Agricultural Experiment Station, Columbia, Mo. Supported in part by funds obtained under Texas Agricultural Experiment Station Bankhead-Jones Project 370, "Breeding Small Grains and Flax for Resistance to Rust and Other Diseases Indigenous to the Humid Climate of South Texas", and U. S. Dept. of Agriculture Bankhead-Jones Project SRF 2–95, "Combining in Wheat the Disease Resistance and Other Desirable Characters of Related Grass Species". Texas Agricultural Experiment Station Technical Contribution No. 1035. Missouri Journal Paper No. 1059. Received for publication July 25, 1947.

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[3]Numbers in parenthesis refer to "Literature Cited", p. 1024.

[4]The original manuscripts and loan copies of these three reports are on file in the library of the South Dakota State College at Brookings, S. D.

emmers, and bread wheats—have 7, 14, and 21 pairs of chromosomes, respectively. Kihara (12) and Sax (38) showed that the wheats comprise an allopolyploid series, in which the 7 chromosome pairs of the einkorns, plus 7 additional pairs, constitute the 14 pairs of the emmers, and that these 14 pairs, plus an additional 7, make up the 21 pairs of the bread wheats. The three different sets of seven chromosomes ("genomes") were early designated A, B, and C (A, B, and D in Japan), the einkorns being AA, the emmers AABB, and the bread wheats AABBCC.

From these findings it appeared that the emmer group must have arisen as an allotetraploid hybrid of a diploid wheat and some related diploid species with the genomes BB, and that the hexaploid group arose later as an allohexaploid hybrid of an emmer wheat and a diploid relative CC. Subsequently, the work of Sax and Sax (40) and of Bleier (2) demonstrated that the C genome was present in the tetraploid species *Aegilops cylindrica*. Following this discovery, it could safely be assumed that the C genome, if still in independent existence, would be found in some diploid species of *Aegilops*. This diploid species has recently been identified as *Ae. squarrosa* L. (23,24).

Realization of the importance of *Aegilops* in the phylogeny of wheat stimulated interest in this genus. Taxonomic monographs of the group were prepared by Zhukovsky (53) and Eig (5). Percival (27, 28), Schiemann (41, 42), Sorokina (47), and others showed that *Aegilops*, like *Triticum*, had species with 7, 14, and 21 pairs of chromosomes. The chromosome numbers here, however, did not correspond in every case with the taxonomic groupings, several sections of the genus having both diploid and tetraploid members. On the basis of comparative chromosome studies, Senjaninova-Korczagina (44) suggested an allopolyploid origin for certain tetraploid species. Kihara (13, 14) and his co-workers, by studying chromosome homologies in inter-specific hybrids, have determined from which diploid species of *Aegilops* the genomes of most of the polyploids were derived, and approximately how much these genomes have been modified since they were incorporated in their respective polyploids.

Cytogenetic investigation of the genus *Agropyron* was begun by Peto (30, 31), who conducted a cytological study of the American species. Beginning about 1928, Tzitzin (49) and other Russian workers began hybridizing the wheats with certain European species of *Agropyron*, notably *A. elongatum* and *A. intermedium* (Host) Beauv. (*A. glaucum* (Desf.) R. et S.). Vakar (50, 51, 52), Peto (32, 33), and others studied chromosome pairing in wheat-*Agropyron* hybrids, and reached the conclusion that the two *Agropyron* species mentioned have at least one genome in common with the tetraploid and hexaploid wheats. There is some evidence, which will be discussed later, that this is the B rather than the A genome.

PRACTICAL RESULTS

Within the last two or three decades, notable progress has been made in transferring desirable characters to *Triticum vulgare* from several other species and genera.

The transfer of characters giving moderate resistance to stem rust from the durum wheats has been reported by Hayes, Parker, and Kurtzweil (9), Goulden (7), and Peterson and Love (29). Harrington and Smith (8), and McFadden (20) were successful in transferring a high degree of resistance to stem rust and leaf rust, and also several other desirable characters, from emmer to the *vulgare* wheats. More recently, Pridham (34) and Shands (45) have obtained promising rust-resistant segregates with *vulgare* characters from crosses between *T. vulgare* and *T. timopheevi*. Sapehin (36) reports having transferred resistance to Hessian fly from durum wheat to *T. vulgare*, and it appears probable that the resistance to Hessian fly now known to occur in Marquillo wheat is a result of its durum parentage.

Other investigators, especially Tzitzin (49) and various of his Russian colleagues, have reported success in transferring desirable characters to *T. vulgare* from certain of the Old World species of *Agropyron*. These characters include perennial nature, great winterhardiness, high forage value, high grain-yielding ability, high protein content, superior milling quality, large kernel size, and resistance to shattering, lodging, drought, heat, frost, and alkali, as well as resistance to several insects and diseases. The literature on *Triticum-Agropyron* hybridization has been reviewed at length by Johnson (10), Smith (46), and Armstrong (1).

Nina Meister (25) and N. G. Meister (26) report having obtained wheat segregates from a wheat-rye cross that were more winterhardy than the wheat parent that went into the cross.

Important characters not at first known to be present in either parent of a cross have sometimes appeared in segregates selected for another purpose. McFadden (20) found resistance to loose smut and bunt in segregates which had been chosen for their resistance to stem rust and leaf rust; and subsequent tests have shown that these same segregates were resistant to mildew, stripe rust, and leaf smut. As mentioned previously, the common wheat variety Marquillo (a *durum*×*vulgare* derivative) is resistant to Hessian fly, although fly resistance was not under consideration at the time Marquillo was selected.

The practical results already accruing from this phase of wheat breeding are little short of astounding. Craigie (4) has recently estimated that the factors for resistance to stem rust obtained from the durums and emmers have, in recent years, resulted in an annual average increase in production of 41,339,000 bushels of wheat valued at $27,242,000 in western Canada alone. Erickson (6) estimates that the factors for resistance to stem rust and leaf rust derived from Yaroslav emmer brought a saving to farmers of the Spring Wheat Belt of Minnesota and the Dakotas in 1944 amounting to more than $135,000,000, and suggests that an additional $75,000,000 might have been saved for the farmers of the Winter Wheat Belt in that year had winter wheats carrying the same factors for resistance been available for general seeding.

DIFFICULTIES ENCOUNTERED IN RADICAL BREEDING

Of the various species of *Triticum* and related genera which have served or might serve as sources of disease resistance or other desirable characters, none forms a fully fertile hybrid with *T. vulgare*. Even the closest relatives, the tetraploid wheats, form relatively infertile hybrids with the hexaploids. The reduction in fertility is due to the fact that none of these relatives has a chromosome complement completely homologous with that of *T. vulgare*, and most have a different chromosome number.

The pentaploid (hexaploid×tetraploid) wheat hybrid is not only the most fertile hybrid involving hexaploid wheat but has also been more thoroughly investigated cytogenetically than any other. At the reduction division in this hybrid, 14 pairs are formed, and seven chromosomes (the *vulgare* C genome) are left unpaired. The unpaired chromosomes are distributed largely at random, with the result that most of the gametes formed carry some but not all of the C chromosomes and are consequently unbalanced. The unbalanced types are mostly nonfunctional on the male side, and on the female side give rise to a considerable proportion of inviable zygotes. The result is usually a 25 to 50% reduction in seed set (9, 37). Furthermore, as many as 40 to 50% of the seeds produced may fail to give rise to fertile F_2 plants because of failure of seed germination and because of inviability or sterility of the resulting plants (39). And finally, the number of useful F_2 plants is further diminished by the fact that most of the F_2 individuals are tetraploid types rather than hexaploid. Obviously, large numbers of F_2 plants must be grown to insure a reasonable chance of obtaining hexaploid types possessing the desired trait from the tetraploid parent. Even after the transfer is accomplished, the breeder may find that undesirable as well as desirable characteristics have been transferred from the tetraploid; and these undesirable characters, if determined by a gene or genes closely linked to the desirable gene, may be very difficult to eliminate.

In hybrids of *T. vulgare* with species or genera to which it is less closely related than to the tetraploid wheats, the same difficulties are encountered but to an enhanced degree. Sterility is usually so high that only through backcrosses can a useful number of seeds be obtained. Some desirable hybrids are not even obtainable because of incompatibility of the parent species in crosses.

Although serious difficulties have been encountered in the use of wide hybrids in wheat, the practical possibilities of this phase of wheat breeding appear to be very great. Improved breeding techniques can presumably be developed which will largely overcome most of the difficulties mentioned. One such new breeding method, arising from a consideration of the allopolyploid nature and apparent trigeneric origin of *T. vulgare*, is described in this paper.

A METHOD FOR RADICAL BREEDING

In the cytological studies referred to in a previous paragraph, it was shown that the A genome of the tetraploid and hexaploid wheats is largely homologous with the genome occurring in the einkorns, or diploid wheats, and probably is derived from one of the three einkorn species, *Triticum monococcum* L., *T. aegilopoides* (Link) Bal., or *T. thaoudar* Reut. ex Boiss.

The recent studies by McFadden and Sears (24) demonstrate that the C genome of the hexaploid wheats is homologous with the genome found in the diploid *Aegilops squarrosa*, and probably is derived from that species.

The specific diploid form that supplied the B genome of the tetraploid and hexaploid wheats has not yet been found. There is considerable evidence, however, from both cytological and morphological considerations that it was an *Agropyron*. Peto's studies (32) indicate that one of the three genomes of *Agropyron intermedium* (*A. glaucum*) is related to either the A or the B genome of the tetraploid and hexaploid wheats. The results of this and numerous other cytological studies (16, 33, 50, 51, 52) involving *A. elongatum* and *A. trichophorum* (Link) Richt. can be interpreted in the same way, although the possibility exists that the approximately seven wheat chromosomes which pair come from both the A and B genomes. McFadden and Sears (24) have recently suggested from morphological evidence that *A. triticeum* Gaertn. may have contributed the B genome to the original free-threshing wheat, *T. antiquorum* (24), grown by the neolithic Swiss Lake dwellers.

It is generally agreed that the genera *Triticum*, *Agropyron*, and *Aegilops* originated from a common ancestor. Of the existing species of these three genera, *Ae. speltoides* appears from morphological and cytological evidence to approach the hypothetical ancestral form most closely. Evolution in the group has evidently consisted mainly in (a) the development of diploid forms divergent from one another in both morphology and chromosome constitution, and (b) the convergence of these forms through the production of allopolyploid hybrids between them. Most of the allopolyploids arising have been of intrageneric origin, but those in the genus *Triticum* have resulted

from hybridization of *Triticum* with *Aegilops* and probably *Agropyron*. Fig. 1 shows diagrammatically the suggested course of the evolutionary processes which gave rise to the cultivated wheats.

From the foregoing it is apparent that the genera *Triticum*, *Agropyron*, and *Aegilops* may each have contributed one genome to the common domesticated wheat, *T. vulgare*. If such be the case, it is probable that desirable characters from these three genera can most readily be worked into *vulgare* wheats by transferring genes from each genus to the particular genome with which its chromosomes have most homology, namely, from the einkorns to the A genome, from the Agropyrons to the B genome, and from *Aegilops* species to the C genome.

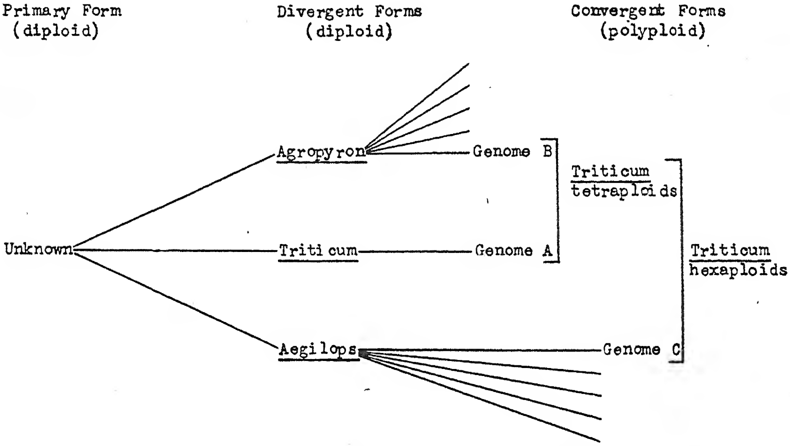

FIG. 1.—Suggested method of origin of the cultivated wheats through processes of divergent and convergent evolution.

In attempts to transfer genes for desirable characters to the appropriate genomes of *T. vulgare*, the following four series of allopolyploids should be useful:

Series 1.—The C genome of *Aegilops squarrosa* added to various tetraploid wheats. The resulting hexaploid types should form much more highly fertile hybrids with *T. vulgare* than do the tetraploids themselves.

Series 2.—Tetraploid wheats combined with the genomes of the various diploid species of *Aegilops* other than *Ae. squarrosa*, and with *Haynaldia villosa* (L.) Schur. The hexaploids thus obtained will form partially fertile hybrids with *T. vulgare* and may permit the transfer of certain desirable characteristics, particularly disease resistance, from *Aegilops* and *Haynaldia* to the C genome. The tetraploid wheat used might be one, such as *T. dicoccoides*, which is susceptible to the rusts and other major diseases of wheat and therefore cannot introduce resistance genes to mask the effects of those transferred from *Aegilops* or *Haynaldia*.

Series 3.—The A and C genomes, which have previously been combined by Sears (43), united with the genomes from various species of

Agropyron. Using the allopolyploids of this series, an effort can be made to transfer desirable genes, blocks of genes, or whole chromo-

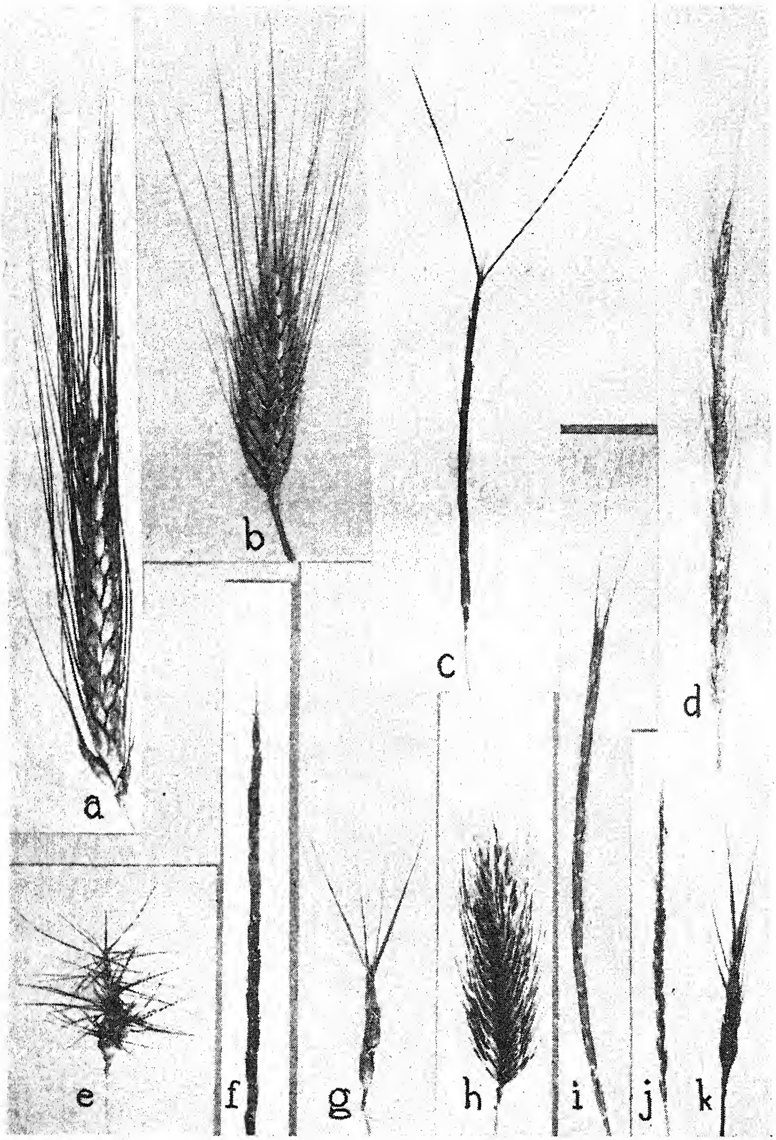

FIG. 2.—Spikes of species used in making the crosses which gave rise to the allohexaploids shown in Figs. 3 and 4. (a) *Triticum dicoccoides*, (b) *T. timopheevi*, (c) *Aegilops caudata*, (d) *Ae. speltoides*, (e) *Ae. umbellulata*, (f) *Ae. squarrosa*, (g) *Ae. comosa*, (h) *Haynaldia villosa*, (i) *Ae. sharonensis*, (j) *Ae. bicornis*, (k) *Ae. uniaristata*. ×0.55.

somes from the *Agropyrons* to the B genome of *T. vulgare*. The addition of the *Secale* and *Haynaldia* genomes to the AACC compound might also be attempted, although cytological studies of various hybrids have indicated little or no association of the chromosomes of *Secale* and *Haynaldia* with those of the B genome. Substitution of whole chromosomes for members of the B genome might be accomplished, however.

Series 4.—A combination of genomes B and C added to the numerous varieties of the wild and cultivated species of einkorn. Crosses of *T. vulgare* with the resulting allohexaploids should permit transfer of einkorn characteristics to the *vulgare* A genome. The possibility of obtaining BBCC is highly speculative, however, since the B genome is not known to exist in any diploid species. Possibly *Agropyron triticeum* could supply the B genome, and an effort to combine this species with the C genome is being made. Attempts to combine *A. triticeum* with the A genome of einkorn have thus far been unsuccessful. Possibly an amphiploid of *Agr. intermedium* (*glaucum*) (BBXXYY ?) × *Ae. squarrosa* (CC) hybridized with *T. vulgare* (AABBCC) would give some BBCC types among selfed offspring—if the hybrid were fertile, which is doubtful because of the relatively large number of unpaired chromosomes to be expected. Hybrids of *T. vulgare* with the amphidiploid *T. aegilopoides* × *Ae. squarrosa* (AACC) are slightly fertile, and might therefore serve for the transfer of einkorn characters to *T. vulgare*.

NEW ALLOPOLYPLOID FORMS[5]

Sixteen new allopolyploid forms have been produced as a part of the program outlined in the preceding section. For all but two of these forms data are available on meiotic chromosome association both before and after chromosome doubling (Table 1), on fertility (Table 2), and on chromosome constitution of offspring (Table 3). In addition, the eight allopolyploids involving *T. dicoccoides* have been crossed with the hexaploid *T. vulgare* and observations made on meiotic chromosome pairing in the resulting hybrids (Table 4).

Further information concerning the various allopolyploids is presented below.

SERIES 1: CC+TETRAPLOID WHEATS

T. dicoccoides var. *spontaneovillosum* Perc. × *Ae. squarrosa* ssp. *eusquarrosa* Eig (Fig. 3a). This form has already been described in detail (24). It probably has no value from a breeding standpoint, for like its parents it is highly susceptible to both stem rust and leaf rust. It is of particular interest because it is a typical *T. spelta* L. in every essential respect.

T. timopheevi × *Ae. squarrosa* (Fig. 4a). This hexaploid is taxonomically very similar to *T. spelta*. It is apparently only slightly less resistant than *T. timopheevi* to leaf and stem rust. Its reaction to the numerous other diseases to which *T. timopheevi* is resistant has not

[5]Seed of any of the allopolyploids described will gladly be released to wheat breeders. The cooperation of others in carrying out any phase of the program outlined will be welcomed.

been determined. Hybrids with *T. vulgare* have been found by Allard (in press) and the writers to be strikingly more fertile than *T. vulgare*

TABLE 1.—*Meiotic chromosome association in hybrids and amphiploids involving tetraploid wheats and various species of Aegilops and Haynaldia.*

Hybrid	Ploidy	No. micro-sporo-cytes ex-amined	Number per microsporocyte of				
			Univalents		Bivalents*		Multi-valents range†
			Range	Aver-age	Range	Aver-age	
T. dicoccoides × *Ae. uniaristata*	2n	200	17–21	20.25	0–2	0.37	0
	4n	100	0–2	0.06	20–21	20.97	0
T. dicoccoides × *Ae. squarrosa*	2n	150	17–21	20.89	0–2	0.05	0
	4n	100	0–4	0.24	17–21	20.88	0
T. dicoccoides × *Ae. umbellulata*	2n	100	19–21	20.82	0–1	0.09	0
	4n	250	0–10	0.53	16–21	20.74	0
T. dicoccoides × *Ae. caudata*	2n	100	11–21	16.46	0–5	2.04	0–2
	4n	50	0–6	0.72	18–21	20.64‡	—
T. dicoccoides × *Ae. speltoides*	2n	50	4–11	7.44	0–8	4.66	0–5
	4n	100	0–4	0.32	19–21	20.84§	—
T. dicoccoides × *Ae. sharonensis*	2n	50	3–13	7.50	2–8	5.18	0–3
	4n	50	0–8	1.30	15–21	20.08	0–2
T. dicoccoides × *Ae. comosa*	2n	100	17–21	19.74	0–2	0.63	0
	4n	50	0–8	1.76	17–21	20.12‡	—
T. dicoccoides × *H. villosa*	2n	200	11–21	19.35	0–5	0.79	0–1
	4n	100	0–10	2.81	16–21	19.58	0–1
T. timopheevi × *Ae. uniaristata*	2n	100	11–21	17.85	0–5	1.51	0–1
	4n	100	0–4	0.51	19–21	20.67	0–1
T. timopheevi × *Ae. caudata*	2n	100	9–21	17.63	0–6	1.58	0–1
	4n	50	0–4	0.66	19–21	20.52	0–1
T. timopheevi × *Ae. bicornis*	2n	200	11–21	17.54	0–5	1.66	0–1
	4n	50	0–4	0.70	16–21	20.20	0–2
T. timopheevi × *Ae. squarrosa*	2n	100	11–21	17.37	0–5	1.71	0–1
	4n	50	0–6	1.46	17–21	20.12	0–1
T. timopheevi × *Ae. umbellulata*	2n	150	7–21	18.12	0–5	1.31	0–2
	4n	75	0–12	2.31	15–21	19.24	0–2
T. timopheevi × *Ae. speltoides*	2n	50	3–9	5.34	4–12	4.64	0–5
	4n	10	0–10	3.70¶	11–17	14.40	0–4

*Practically all bivalents in the 2n hybrids were of the open type, except an average of 0.60 closed in *T. dicoccoides* × *Ae. speltoides*, 0.40 in *T. dicoccoides* × *Ae. sharonensis*, and 1.64 in *T. timopheevi* × *Ae. speltoides*.

†Predominantly trivalents in the 2n hybrids, quadrivalents and trivalents in the amphiploids.

‡Includes a low frequency of multivalents.

§Includes a considerable frequency of multivalents.

¶The inclusion of 40 additional microsporocytes in the sample changed this value to 3.16.

TABLE 2.—*Fertility of primary florets of amphiploids grown in greenhouse at Columbia, Mo.*

Amphiploid	Season	No. of plants	No. of florets	Percentage fertility
T. dicoccoides × *Ae. uniaristata*	1943	2	245	89.0
T. dicoccoides × *Ae. squarrosa*	1943	1	108	95.4
T. dicoccoides × *Ae. umbellulata*	1941	6	249	97.6
T. dicoccoides × *Ae. caudata*	1942	6	314	96.5
T. dicoccoides × *Ae. speltoides*	1941	3	152	88.8
	1942	2	291	92.1
T. dicoccoides × *Ae. sharonensis*	1941	2	92	78.3
	1942	6	294	80.6
T. dicoccoides × *Ae. comosa*	1941	2	177	10.2
T. dicoccoides × *H. villosa*	1943	4	183	14.7
T. timopheevi × *Ae. uniaristata*	1943	5	207	93.2
T. timopheevi × *Ae. caudata*	1942	5	239	97.5
T. timopheevi × *Ae. bicornis*	1942	5	297	92.9
T. timopheevi × *Ae. squarrosa*	1943	3	90	84.4
T. timopheevi × *Ae. umbellulata*	1942	3	98	78.6
T. timopheevi × *Ae. speltoides*	1942	2	307	93.8

×*T. timopheevi*. This increased fertility enhances the chance of transferring *timopheevi's* factors for disease resistance to *T. vulgare*.

SERIES 2: TETRAPLOID WHEATS+*Aegilops* GENOMES

T. dicoccoides×*Ae. caudata* L. var. *polyathera* Boiss. (Fig. 3b). Highly susceptible to leaf rust and to certain races of stem rust. Possibly resistant to Hessian fly, for E. T. Jones (personal communication) found resistance in *Ae. caudata*. The rachis is relatively nonfragile, having only a slight tendency to break at the base of the

TABLE 3.—*Chromosome constitution of offspring of amphiploid plants.*

Amphiploid	Number of offspring with			
	21″	20″1′	19″2′	Other
T. dicoccoides × *Ae. uniaristata*	12	—	—	—
T. dicoccoides × *Ae. squarrosa*	7	4	—	17″4′ (1) 15″6′ (1)
T. dicoccoides × *Ae. umbellulata*	6	—	—	—
T. dicoccoides × *Ae. caudata*	5	1	—	—
T. dicoccoides × *Ae. speltoides*	9	6	—	18″2‴ (1)
T. dicoccoides × *Ae. sharonensis*	8	—	1	20″1‴ (1) 19″1‴ 1′ (1)
T. dicoccoides × *Ae. comosa*	2	1	1	?* (1)
T. dicoccoides × *H. villosa*	7	3	—	—
T. timopheevi × *Ae. uniaristata*	3	2	—	—
T. timopheevi × *Ae. caudata*	4	2	—	—
T. timopheevi × *Ae. bicornis*	6	—	—	—
T. timopheevi × *Ae. squarrosa*	3	—	—	18″3′ (1)
T. timopheevi × *Ae. umbellulata*	5	—	—	?* (1)
T. timopheevi × *Ae. speltoides*	3	2†	—	2n=40 (1)

*Died before maturity; presumably of abnormal constitution.
†Including 1 plant with 2n=41 having undetermined pairing relationships.

spike. Highly fertile. Hybrids with *T. vulgare* show at least three chromosomes of *Ae. caudata* paired with the C genome of *T. vulgare*.

T. dicoccoides × *Ae. comosa* Sibth. and Sm. ssp. *heldreichii* (Boiss.) Eig (Fig. 3c). Fertility low. Probably resistant to leaf rust, for *Ae. comosa* is highly resistant (11). Hybrids with *T. vulgare* have indicated little or no association of the *comosa* chromosomes with genome C. This failure of pairing may have been due, however, to other causes

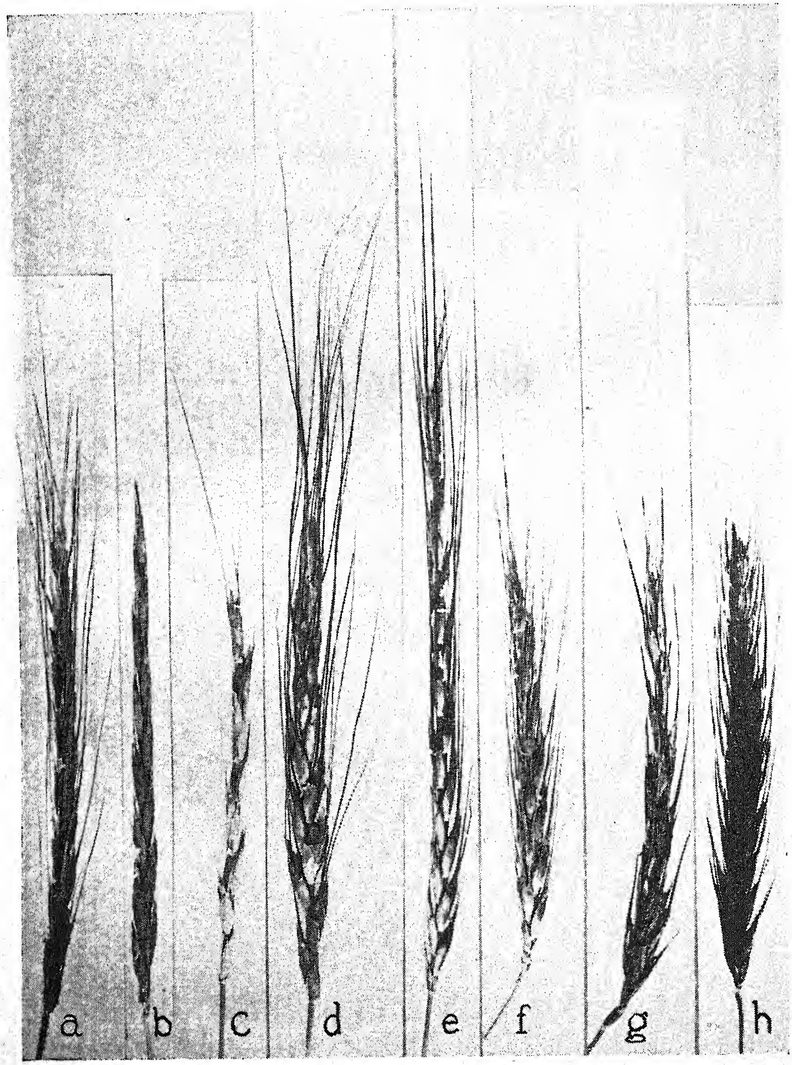

Fig. 3.—Allohexaploid hybrids involving T. *dicoccoides* crossed with (a) *Ae. squarrosa*, (b) *Ae. caudata*, (c) *Ae. comosa*, (d) *Ae. sharonensis*, (e) *Ae. speltoides*, (f) *Ae. umbellulata*, (g) *Ae. uniaristata*, (h) *H. villosa*. × 0.55.

than lack of chromosome homology, for Kihara and Lilienfeld (15) found up to seven tight pairs in *Ae. comosa*×*Ae. squarrosa.*

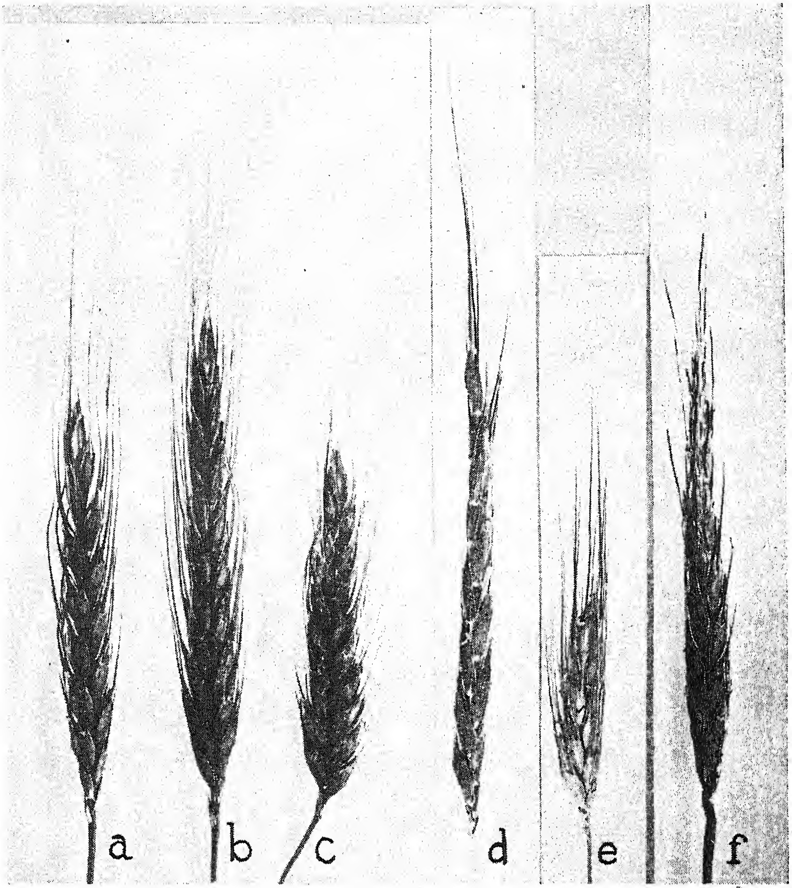

Fig. 4.—Allohexaploid hybrids involving *T. timopheevi* crossed with (a) *Ae. squarrosa*, (b) *Ae. speltoides*, (c) *Ae. bicornis*, (d) *Ae. caudata*, (e) *Ae. umbellulata*, (f) *Ae. uniaristata.* ×0.65.

T. dicoccoides×*Ae. sharonensis* Eig var. *typica* Eig (Fig. 3d). Fertility fair to good. Brittle rachis. Solid stems. Highly susceptible to leaf rust, but resistant to certain races of stem rust in tests at the Minnesota Experiment Station. Hybrids with *T. vulgare* show at least two *sharonensis* chromosomes able to pair with chromosomes of genome C.

T. dicoccoides×*Ae. speltoides* Tausch var. *ligustica* (Savign.) Fiori (Fig. 3e). Extremely resistant to stem and leaf rusts. Promising for winter pasture, because highly vigorous, freely tillering, long leaved, frost resistant, and non-"bolting" (no tendency to flower during

TABLE 4.—*Meiotic chromosome association in hybrids of amphiploids with Triticum vulgare.*

Amphiploid	*T. vulgare* parent	No. of micro-sporocytes examined	Number per microsporocyte of								Maximum pairing
			Univalents		Bivalents		Trivalents		Quadrivalents		
			Range	Average	Range	Average	Range	Average	Range	Average	
T. dicoccoides × *Ae. squarrosa*	Chinese ♀	50	0–8	2.08	17–21	19.96	0	0.00	0	0.00	21″
T. dicoccoides × *Ae. speltoides*	Chinese ♀	15	3–14	7.60	9–17	13.93	0–4	1.73	0–2	0.33	15″3‴ 3′
T. dicoccoides × *Ae. caudata*	Webster ♀	20	8–15	10.65	12–17	14.40	0–2	0.65	0–1	0.15	17″ 8′
T. dicoccoides × *Ae. sharonensis*	Chinese ♂	20	9–20	14.20	10–15	12.95	0–3	0.50	0–1	0.10	15″1‴ 9′
T. dicoccoides × *Ae. umbellulata*	Chinese ♀ Webster ♀	12 20	14–20 12–24	17.17 17.05	11–14 9–15	12.42 12.40	0 0–1	0.00 0.05	0 0	0.00 0.00	14″ 14′ 15″ 12′
T. dicoccoides × *Ae. comosa*	Chinese ♂ Webster ♂	20 20	13–24 14–24	18.00 19.00	8–13 8–13	11.45 10.70	0–1 0–1	0.10 0.20	0–1 0–1	0.20 0.25	13″1‴ 13′ 12″1″″ 14′
T. dicoccoides × *Ae. uniaristata*	Chinese ♀	25	10–15	12.72	12–16	14.52	0–1	0.08	0	0.00	16″ 10′
T. dicoccoides × *H. villosa*	Chinese ♀	50	12–22	16.12	9–15	12.34	0–1	0.24	0–1	0.12	15″ 12′

warm periods in winter). Rachis relatively nonfragile. Fair to good fertility. Considerable cytological and consequent morphological instability (Table 3), due to homologies of *speltoides* chromosomes with those of the A and B genomes. Hybrids with *T. vulgare* show at least four *speltoides* chromosomes pairing with members of the *vulgare* C genome, and in one season set an average of 15 seeds per spike. Should form fertile hybrids with the preceding amphiploid *T. dicoccoides*×*Ae. sharonensis*, since *speltoides* and *sharonensis* chromosomes pair quite freely.

T. dicoccoides×*Ae. umbellulata* Zhuk. (Fig. 3f). Highly fertile. Rachis nonfragile except at base. Moderately resistant to leaf rust, but highly susceptible to stem rust. Only one pair observed between *umbellulata* and C-genome chromosomes in hybrids with *T. vulgare*.

T. dicoccoides×*Ae. uniaristata* Vis. (Fig. 3g). Good fertility. Rachis nonfragile except at base. Susceptible to stem rust. Resistant to leaf rust. Hybrids with *T. vulgare* show at least two chromosomes of *uniaristata* pairing with members of the C genome.

T. dicoccoides×*Haynaldia villosa* (Fig. 3h). Low fertility. Fragile rachis. Probably resistant to stem and leaf rust, since *H. villosa* is resistant (Stakman, *et al.*, unpublished; 11). One *Haynaldia* chromosome occasionally pairs with a C-genome chromosome in hybrids with *T. vulgare*.

T. dicoccum Schrank var. Vernal×*Ae. sharonensis*. Similar to *dicoccoides-sharonensis* in most respects, but may carry additional resistance to stem rust, since the *dicoccum* parent is characterized by mature-plant resistance and by seedling resistance to most races.

T. persicum Vav.×*Ae. sharonensis*. Similar to *dicoccoides-sharonensis*, but free-threshing; rachis slightly less fragile. Probably resistant to mildew, like *T. persicum*.

T. timopheevi×*Ae. bicornis* (Forsk.) Jaub. and Spach. var. *typica* (Post) Eig (Fig. 4c). Good fertility, but rachis extremely brittle. Vigorous, in contrast to the hybrid *T. dicoccoides*×*Ae. bicornis*, which dies in the seedling stage. Highly resistant to stem and leaf rust. Resistance of *Ae. bicornis* to aphids, which is due to scabrous condition of vegetative parts (presence of sharp, geotropic barbs), is not found in the allohexaploid, where the barbs are replaced by fine hairs, such as exhibited by *T. timopheevi* itself. On the other hand, an amphidiploid hybrid between a glabrous form of *T. monococcum* and *Ae. bicornis* shows an actual amplification of the barbing effect, suggesting that a glabrous tetraploid×*Ae. bicornis* might yield a highly scabrous hexaploid immune from aphids.

T. timopheevi×*Ae. caudata* (Fig. 4d), ×*Ae. speltoides* (Fig. 4b),× *Ae. umbellulata* (Fig. 4e), and ×*Ae. uniaristata* (Fig. 4f). These amphiploids are similar morphologically to those involving *T. dicoccoides* and the same *Aegilops* species but carry the genes for disease resistance of *T. timopheevi* in addition to those of the *Aegilops* species. They are not as useful, however, as those involving *T. dicoccoides* for transferring factors from *Aegilops* to the C genome of *T. vulgare*. This is because the fertility of the hybrids of the amphiploids with *T. vulgare* is lower, due to the comparatively poor homology of the

timopheevi chromosomes with those of the B and possibly the A genomes of *T. vulgare*.

SERIES 3: AACC+*Agropyrons*

The basic combination, AACC, has been obtained in an amphidiploid of *T. aegilopoides* var. *baidaricum* Flaksb.×*Ae. squarrosa*.

SERIES 4: BBCC+EINKORNS

The desired basic compound, BBCC, has not been obtained.

SUMMARY

The transfer of desirable characteristics to hexaploid wheats from tetraploid wheats, Agropyrons, and rye has been reported by various investigators. The diploid wheats (einkorns) and the genera *Aegilops* and *Haynaldia* also have attributes which would be very useful if transferred to hexaploid wheats.

The A genome of hexaploid wheats is evidently derived from einkorn, the C from *Ae. squarrosa*, and the B perhaps from *Agropyron*. The best chance of transferring desirable characters from einkorn is assumed, therefore, to be to the A genome, from *Agropyron* to the B genome, and from *Aegilops* to the C genome.

To overcome sterility and other difficulties, four series of artificially produced allohexaploids, the first two of which are partially completed, are suggested as basic material for the transfer of characters from other species and genera to *T. vulgare* as follows:

1. Amphiploids of *Ae. squarrosa* with various tetraploid wheats for transfer of characteristics from the tetraploids to the A and B genomes.
2. Amphiploids of tetraploid wheats with various diploid species of *Aegilops* for transfer of *Aegilops* characters to the C genome.
3. Amphiploids of the A+C combination (einkorn×*Ae. squarrosa*) with various species of *Agropyron* for transfer of *Agropyron* characters to the B genome.
4. Amphiploids of the constitution BBCC (if obtainable) plus various species and varieties of einkorn, for transfer of einkorn characters to the A genome.

The following amphiploids are described: *T. dicoccoides*×*Ae. squarrosa*, *Ae. caudata*, *Ae. comosa*, *Ae. sharonensis*, *Ae. speltoides*, *Ae. umbellulata*, *Ae. uniaristata*, and *Haynaldia villosa; T. dicoccum* and *T. persicum*×*Ae. sharonensis; T. timopheevi*×*Ae. squarrosa*, *Ae. bicornis*, *Ae. caudata*, *Ae. speltoides*, *Ae. umbellulata*, and *Ae. uniaristata*.

LITERATURE CITED

1. ARMSTRONG, J. M. Investigations in *Triticum-Agropyron* hybridization. Empire Jour. Exp. Agr., 13:41–53. 1945.
2. BLEIER, H. Zytologische Untersuchungen an seltenen Getreide- und Rübenbastarden. Ztschr. f. ind. Abstam.- u. Vererbungsl., Suppl. 1:447–452. 1928.
3. CARLETON, M. A. Emmer: A grain for the semiarid regions. U. S. D. A. Farmers' Bul. 139. 1901.
4. CRAIGIE, J. H. Increase in production and value of the wheat crop in Manitoba and eastern Saskatchewan as a result of the introduction of rust resistant wheat varieties. Sci. Agr., 25:51–64. 1944.

5. EIG, A. Monographisch-kritische Übersicht der Gattung *Aegilops*. Repert. Spec. Nov. Regni Vegetabilis. Fedde, Beih. 55. 1929.
6. ERICKSON, A. W. McFadden's Hope. Field Notes Crop Reporting Service, 4641 Xerxes Ave. S., Minneapolis, Minn. 1945.
7. GOULDEN, C. H. Breeding rust resistant varieties of wheat—fundamental aspects of the problem. Sci. Agr., 10:258–267. 1929.
8. HARRINGTON, J. B., and SMITH, W. K. The inheritance of reaction to black stem rust of wheat in a *dicoccum* × *vulgare* cross. Can. Jour. Res., 1:163–188. 1929.
9. HAYES, H. K., PARKER, J. H., and KURTZWEIL, C. Genetics of rust resistance in crosses of varieties of *Triticum vulgare* with varieties of *T. durum* and *T. dicoccum*. Jour. Agr. Res., 19:523–542. 1920.
10. JOHNSON, L. P. V. Hybridization of *Triticum* and *Agropyron*. IV. Further crossing results and studies on the F_1 hybrids. Can. Jour. Res., C, 16: 417–444. 1938.
11. JOHNSTON, C. O. Some species of *Triticum* and related grasses as hosts for the leaf rust of wheat, *Puccinia triticina* Eriks. Trans. Kansas Acad. Sci., 43: 121–132. 1940.
12. KIHARA, H. Über cytologische Studien bei einigen Getreidearten. I. Spezies-Bastarde des Weizens und Weizenroggen-Bastard. Bot. Mag. Tokyo, 32: 17–38. 1919.
13. ————. Verwandtschaft der *Aegilops*-Arten im Lichte der Genomanalyse. Ein Überblick. Züchter, 12:49–62. 1940.
14. ————. [The classification of *Aegilops* in the light of genome assay.] Chart circulated by Kihara. 1945.
15. ————, and LILIENFELD, F. Genomanalyse bei *Triticum* und *Aegilops*. VI. Weitere Untersuchungen an *Aegilops* × *Triticum*- und *Aegilops* × *Aegilops*-Bastarden. Cytologia, 6:195–216. 1935.
16. LOVE, R. M., and SUNESON, C. A. Cytogenetics of certain *Triticum-Agropyron* hybrids and their fertile derivatives. Amer. Jour. Bot., 32:451–456. 1945.
17. MCFADDEN, E. S. Wheat-rye hybrids. Jour. Her., 8:335–336. 1917.
18. ————. Confessions of a plant breeder. A paper read at a meeting of the Kiwanis Club of Webster, S. D., in the winter of 1925–1926. 1926.
19. ————. Possibilities and difficulties in the field of radical wheat crossing. Rpt. 1st Ann. Hard Spring Wheat Conf., Fargo, N. D.: 58–61. 1928.
20. ————. A successful transfer of emmer characters to *vulgare* wheat. Jour. Amer. Soc. Agron., 22:1020–1034. 1930.
21. ————. Crosses of wheat with closely related genera. Rpt. 4th Hard Spring Wheat Conf., Minneapolis, Minn.: 45. 1934. (Abstract)
22. ————. What is being done with species hybrids in Texas—some new synthetic hexaploid wheats. Rpt. 5th Hard Red Winter Wheat Conf., Manhattan, Kansas:2–3. 1945. (Abstract)
23. ———— and SEARS, E. R. The artificial synthesis of *Triticum spelta*. Rec. Gen. Soc. Amer., 13:26–27. 1944.
24. ————, ————. The origin of *Triticum spelta* and its free-threshing hexaploid relatives. Jour. Her., 37:81–89; 107–116. 1946.
25. MEISTER, NINA. The principal results in the study of wheat-rye hybrids. Zhur. Opytn. Agron. Ingo-Vostoka, 3:121–130. 1926.
26. MEISTER, N. G. Rye-wheat hybrids and their importance in breeding. Selektsija:Semonavodstvo, No. 2: 34–36. 1936.
27. PERCIVAL, J. Chromosome numbers in *Aegilops*. Nature, 111:810. 1923.
28. ————. The morphology and cytology of some hybrids of *Aegilops ovata* L. × wheats. Jour. Gen., 17: 49–68. 1926.
29. PETERSON, R. F., and LOVE, R. M. A study of the transference of immunity to stem rust from *Triticum durum* var. Iumillo to *T. vulgare* by hybridization. Sci. Agr., 20:608–623. 1940.
30. PETO, F. H. Chromosome numbers in the *Agropyrons*. Nature, 124:181–182. 1929.
31. ————. Cytological studies in the genus *Agropyron*. Can. Jour. Res., 3: 428–448. 1930.
32. ————. Hybridization of *Triticum* and *Agropyron*. II. Cytology of the male parents and F_1 generation. Can. Jour. Res., C, 14:203–214. 1936.
33. ————. Fertility and meiotic behaviour in F_1 and F_2 generations of *Triticum-Agropyron* hybrids. Genetics, 24:93. 1939.

34. PRIDHAM, J. T. A successful cross between *Triticum vulgare* and *Triticum timopheevi*. Jour. Austr. Inst. Agr. Sci., 5:160–162. 1939.
35. SAKAMURA, T. Kurze Mitteilung über die Chromosomenzahlen und die Verwandtschaftsverhältnisse der *Triticum*-Arten. Bot. Mag. Tokyo, 32:151–154. 1918.
36. SAPEHIN, A. A. Hylogenetic investigations of the *vulgare* group in *Triticum*. Bul. Appl. Bot., Genet., Plant Breed., 19:127–166. 1928.
37. SAX, K. Sterility in wheat hybrids. I. Sterility relationships and endosperm development. Genetics, 6:399-416. 1921.
38. ———. Sterility in wheat hybrids. II. Chromosome behavior in partially sterile hybrids. Genetics, 7: 513–552. 1922.
39. ———. Sterility in wheat hybrids. III. Endosperm development and F_2 sterility. Genetics, 7:553–558. 1922.
40. ———, and SAX, H. J. Chromosome behavior in a genus cross. Genetics, 9:454–464. 1924.
41. SCHIEMANN, E. Chromosomenzahlen in der Gattung *Aegilops*. Ber. deut. bot. Ges., 46:324–328. 1928.
42. ———. Zytologische Beiträge zur Gattung *Aegilops*. Chromosomenzahlen und Morphologie. Ber. deut. bot. Ges., 47:164–181. 1929.
43. SEARS, E. R. Amphidiploids in the seven-chromosome *Triticinae*. Mo. Agr. Exp. Sta. Res. Bul. 336. 1941.
44. SENJANINOVA-KORCZAGINA, M. Karyo-systematical investigations of the genus *Aegilops* L. Bul. Appl. Bot., Genet., Plant Breed., Ser. 2, No. 1:1–90. 1932.
45. SHANDS, R. G. Disease resistance of *Triticum timopheevi* transferred to common wheat. Jour. Amer. Soc. Agron., 33:709–712. 1941.
46. SMITH, D. C. Intergeneric hybridization of cereals and other grasses. Jour. Agr. Res., 64:33–47. 1942.
47. SOROKINA, O. N. On the chromosomes of *Aegilops* species. Bul. Appl. Bot., Genet., Plant Breed., 19:523–532. 1928.
48. TZITZIN, N. V. The *Triticum-Agropyron* hybrids. Lenin Acad. Agr. Sci., Siberian Inst. Grain Cult. Omsk: 101. 1933.
49. ———. Distant hybridization—the chief method of breeding. Breed. and Seed Grow., 10:4–7. 1940. [Abstract in Plant Breed. Absts., 11:942. 1941.]
50. VAKAR, B. A. Cytologische Untersuchung der ersten Generation der Weizen-Queckengrasbastarde. Züchter, 7:199–206. 1935.
51. ———. Cytologische Untersuchung über F_1 der Weizen-Queckengras Bastarde. Cytologia, 7:293–312. 1936.
52. ———. Cytologische Untersuchung der selbstfertilen ersten Generation der Weizen-Queckengras Bastarde. Cytologia, 8:67–90. 1937.
53. ZHUKOVSKY, P. M. A critical-systematical survey of the species of the genus *Aegilops* L. Bul. Appl. Bot., Genet., Plant Breed., 18: 417–609. 1928.

Results from Uniform Winterhardiness Nurseries of Oats Grown from 1942 to 1946[1]

Franklin A. Coffman[2]

THE cooperative uniform winterhardiness oat nurseries have been grown for 20 years. Results for the 10-year period, 1927–36, and for the 5 years, 1937–41, have been published (1, 2, 3).[3] This paper reports data obtained on experiments grown during the period 1942 to 1946, inclusive, bringing the results up to date. During the 5 years 1942–46 killing of a differential nature was reported in 139 of the 224 nurseries sown.

During the first 10 years of these experiments each variety was planted at the rate of 100 kernels per row about 2 inches apart in rows usually 18 feet in length. From 1937 to 1941 two rows of each variety or strain were seeded, 50 seeds per row. Throughout the 15 years the percentages of survival were based on actual counts made in the fall and in the spring. Starting in the fall of 1941, the former method of seeding has been continued only in the deep South, whereas on the stations farther north each entry in the nursery is sown in duplicate 5-foot rows, 5 grams of seed per row being sown. In these latter nurseries survival percentages are based on estimates of stand in the fall and in the spring.

Actual counts of plants tend to disclose small differences which might otherwise be overlooked in the South where little killing occurs. Also, in the more southern areas, growth may continue throughout the winter and differences in growth rate could easily be mistaken for differences in hardiness. Although the summary data assembled herewith include the results from both types of nurseries, the data obtained from the individual stations have tended to show that, in general, the two methods give similar results.

In general, the states and stations which cooperated during the previous period have cooperated in these more recent experiments. Most of the stations in the Pacific Northwest have discontinued these experiments, whereas a number of new stations in the South have joined in the cooperation. In recent years some 40 to 45 stations have cooperated each year. The location of each nursery, the number of years grown during the period 1942 to 1946, and the names of the cooperators are given in Table 1.

Winterkilling was severe only in the winter of 1942–43. Reference to previously published data (2, 3) indicates that it likely was the most rigorous winter for oats since 1936 and that it was one of the four most disastrous seasons for fall-sown oats during the 20 years in which these experiments were conducted. Averages only are reported

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[3]Figures in parenthesis refer to "Literature Cited", p. 1035.

TABLE 1.—*Stations at which winterhardiness nurseries were grown from 1942 to 1946, inclusive, and the names of cooperators.*

Location: State	Location: Place	Cooperators*	No. of years grown, 1942–46, incl.
Ala.	Auburn	E. L. Mayton	1
	Fairhope	Harold F. Yates	5
Ark.	Fayetteville	W. J. Wiser, C. K. McClelland, Tildon Easley	5
	Jonesboro	E. A. Vestal	1
	Stuttgart	C. Roy Adair	5
Fla.	Quincy	Raymond C. Bond, W. H. Chapman, J. D. Warner	5
Ga.	Blairsville	R. P. Bledsoe, U. R. Gore	2†
	Experiment	R. P. Bledsoe, U. R. Gore, L. N. Skold	5
Ind.	Bedford	R. M. Caldwell, L. E. Compton	4
	Evansville	R. M. Caldwell, L. E. Compton	1
	Lafayette	R. M. Caldwell, L. E. Compton	5
	Princeton	R. M. Caldwell, L. E. Compton	1
Ill.	Alhambra	Geo. H. Dungan	1
	Urbana	Geo. H. Dungan	1
Ky.	Lebanon	L. M. Josephson	2
	Lexington	L. M. Josephson	3
La.	Baton Rouge	John Gray	4†
	Calhoun	Dawson M. Johns	5†
	St. Joseph	C. B. Haddan, John A. Hendrix	3‡
Md.	Beltsville	J. W. Taylor, W. S. Becker	5
	College Park	R. G. Rothgeb	5
Miss.	Scott	Grafton F. Henry	1
	State College	J. Fred O'Kelly	5
	Stoneville	P. W. Gull	5
	West Point	J. Fred O'Kelly, T. F. Akers	5
Mo.	Columbia	J. M. Poehlman	5
	Sikeston	B. M. King	5
N. J.	New Brunswick	Robt. S. Snell, G. H. Ahlgren, E. L. Spencer, H. B. Sprague	5
N. C.	McCullers	G. K. Middleton	3
	Statesville	G. K. Middleton, J. W. Hendricks	5
	Swannanoa	G. K. Middleton	2
	Waynesville	G. K. Middleton	2
N. Y.	Ithaca	H. H. Love	1
Ohio	Carpenter	C. A. Lamb, H. Powelson	5†
	Columbus	C. A. Lamb	1
	Germantown	C. A. Lamb	1
	Wooster	C. A. Lamb	5
Okla.	Cherokee	A. M. Schlehuber, C. B. Cross	3†
	Goodwell	O. Clay Terry, Clyde H. Jameson	3
	Lawton	W. M. Osborn, R. G. Dahms	5
	Lone Grove	A. M. Schlehuber, C. B. Cross, G. W. Statton	3§
	Stillwater	A. M. Schlehuber, C. B. Cross	4
	Woodward	V. C. Hubbard	5
Ore.	Corvallis	R. E. Fore, D. D. Hill	3†
S. C.	Clemson	W. R. Paden	5
	Hartsville	R. S. Cathcart, Geo. J. Wilds	5
	Westminster	S. J. Hadden	5
Tenn.	Columbia	N. I. Hancock	2
	Crossville	N. I. Hancock	5
	Greenville	N. I. Hancock	1
	Jackson	N. I. Hancock	3

TABLE 1.—*Concluded.*

Location		Cooperators*	No. of years grown, 1942–46, incl.
State	Place		
Tenn.	Knoxville	N. I. Hancock	5
	Springfield	N. I. Hancock	1
Texas	Amarillo	I. M. Atkins	1
	Bushland	David A. Reid	1
	College Station	E. S. McFadden	5
	Denton	I. M. Atkins	5
	Greenville	Dalton R. Hooton	5
	Temple	H. O. Hill	3
Va.	Blacksburg	T. M. Starling	2
	Glade Spring	C. W. Ryburn	3
Wash.	Pullman	O. E. Barbee	2‡
	Puyallup	Karl Baur, O. E. Barbee	1
W. Va.	Kearneysville	Collins Veatch, Roland O. Weibel, J. W. Taylor	3§
	Lakin	G. G. Pohlman, Roland Weibel	4§
	Morgantown	Collins Veatch, G. G. Pohlman, Roland O. Weibel	4§
	Wardensville	Collins Veatch, G. G. Pohlman	2
	Total		224

*Persons transmitting data to U. S. Dept. of Agr.; cooperator for 1946 listed first, the others follow.
†Planted but no data received one year.
‡Planted too late one year to take full data.
§Data incomplete for one year consequently omitted.

in this paper and no attempt is made to determine whether different varieties respond differently on different stations and different soils types, or whether varieties are better adapted to one region than to another. During the 5-year period a sufficiently large number of cooperators were included each season to supply ample data to determine rather accurately the relative hardiness of a large number of entries even when included for only one or two seasons. One of the most valued features of the uniform winterhardiness nurseries is to determine the relative hardiness of new oat strains.

RESULTS OBTAINED

Average survival data on the 70 varieties and selections included in the experiments during the 5-year period are listed in Table 2. Data are included only from nurseries in which killing of a differential nature took place. Of the 70 entries included in the tests approximately half would usually be classed morphologically as belonging to *Avena byzantina* and half to *A. sativa*. In more recent years an attempt has been made to maintain a balance of approximately equal numbers of the two types. With the increasing hybridization of oats many new varieties represent a blend of the two species. As a consequence, data on varieties and selections included in Table 2 are presented primarily on the basis of the parental strain most closely approached in

TABLE 2.—*Summarized annual percentage survivals of winter oat varieties and selections and average survivals compared with that of the Winter Turf variety.*

Variety or selection	C. I. No.	1942 (31 stations)	1943 (30 stations)	1944 (28 stations)	1945 (18 stations)	1946 (32 stations)	Weighted average survival				Number of test	
							Variety	Winter Turf (same tests)	Percentage Winter Turf			
									1942–46	1926–46	1942–46	1926–46
Black Winter												
Tech (V.P.I. No. 1)	947	82.9	65.3	72.7	77.4	72.4	73.9	69.5	106.3	102.0	139	412
Culberson and Culberson Hybrids												
Hairy Culberson	2505	86.8	64.9	80.3	81.0	75.9	77.5	69.5	111.5	107.7	139	411
Bicknell	3218	84.3	70.4	78.3	82.9	75.2	77.8	69.5	111.9	107.0	139	412
Wintok (Hairy Culberson×Fulghum C.I. 2500)	3424	87.3	73.5	83.2	—*	84.6	82.2	68.0	120.9	114.8	121	233
(Seg.×35 D V)×Hairy Culberson	4317	—	—	66.5	—	—	66.5	71.4	93.1	—	28	—
Winter Turf and Winter Turf Hybrids												
Winter Turf (check)	3296	80.1	51.2	71.4	79.8	68.9	69.5	69.5	100.0	100.0	139	412
Pioneer	3427	79.2	—	—	—	—	79.2	80.1	98.9	101.8	31	144
Fulghum (C.I. 2500)×Winter Turf 203–5	4207	—	53.9	—	—	—	53.9	51.2	105.3	—	30	—

Lee and Lee Hybrids												
Lee	2042	79.8	51.5	63.1	71.9	72.0	67.5	69.5	97.1	97.0	139	412
DeSoto	3923	68.9	39.3	61.1	55.8	61.3	57.5	69.5	82.7	—	139	—
Lega	3979	60.7	35.7	52.6	—	—	49.7	67.6	73.5	—	89	—
Lega Sel. 16	4544	—	—	—	—	44.4	44.4	68.9	64.4	—	32	—
Lelina	3404	68.4	39.0	—	—	—	53.9	65.9	81.8	—	61	—
Levic	3384	66.0	—	—	—	—	66.0	80.1	82.4	—	31	—
Leroy	3398	—	—	59.9	64.2	—	61.6	74.7	82.5	83.6	46	77
Letoria	3392	75.4	53.6	68.8	72.6	67.1	67.1	69.5	96.5	99.9	139	221
Lemont	4080	73.1	—	—	—	—	73.1	80.1	91.3	—	31	—
Quincy Gray (Quincy 2)	4078	68.3	—	—	—	—	68.3	80.1	85.3	—	31	—
Stanton Strain 1	3855	73.9	48.4	—	—	—	61.4	65.9	93.2	98.0	61	90
Stanton Strain (40–33)	3944	68.6	—	—	—	—	68.6	80.1	85.6	—	31	—
Stanton Strain (43–33)	4315	—	—	59.5	—	—	59.5	71.4	83.3	—	28	—
Stanton Strain 2	4390	—	—	—	66.6	—	66.6	79.8	83.5	—	18	—
Stanton Strain 3	4543	—	—	—	—	63.0	63.0	68.9	91.4	—	32	—
Florilee	4208	—	38.6	—	—	—	38.6	51.2	75.4	—	30	—
Fulwin×(Lee-Victoria) Sel. 3828	4204	—	56.1	—	—	—	56.1	51.2	109.6	—	30	—
(Lee-Victoria)×Fulwin Sel. 3788	4316	—	—	59.8	68.5	67.2	64.8	72.3	89.6	—	78	—
(Lee-Victoria)×Fulwin Sel. 2814–4	4381	—	—	—	67.5	—	67.5	79.8	84.6	—	18	—
(Lee-Victoria)×Fulwin Sel. 2817	4382	—	—	—	71.5	55.0	60.9	72.8	83.7	—	50	—
Fulwin×(Lee-Victoria) Sel. 3770	4383	—	—	—	77.6	63.2	68.4	72.8	94.0	—	50	—
Fulwin×(Lee-Victoria)	4219	—	—	62.5	—	—	62.5	71.4	87.5	—	28	—
(Lee-Victoria)×Fulwin	4550	—	—	—	—	67.5	67.5	68.9	98.0	—	32	—
(Lee-Victoria)×Fulwin	4551	—	—	—	—	59.6	59.6	68.9	86.5	—	32	—
Fulghum and Fulghum Hybrids												
Fulghum	708	66.6	33.1	53.6	48.7	48.7	50.3	69.5	72.4	88.4	139	412
Fulghum (winter type)	2499	83.8	65.0	77.6	75.5	71.6	74.6	69.5	107.3	103.3	139	412
Fulwin	3168	87.9	70.1	79.8	79.8	77.3	78.9	69.5	113.5	111.4	139	274
Forkedeer	3170	—	—	74.0	78.4	—	75.7	74.7	101.3	103.4	46	68
Fulghum H C 726×Bond	4076	61.7	40.5	—	—	—	51.3	65.9	77.8	—	61	—
(Fulghum-Markton)×(Victoria-Rich.)	4000	48.1	—	—	—	—	48.1	80.1	60.0	—	31	—
Victorgrain (39–2)	3692	66.8	—	—	—	—	66.8	80.1	83.4	86.7	31	89
Fultex	3531	66.7	40.1	55.4	55.1	48.1	52.9	69.5	76.1	81.7	139	197
Fulghum×Victoria Sel. 696	4203	—	50.0	—	—	—	50.0	51.2	97.7	—	30	—
Victorgrain Strain 3	4098	—	38.4	—	—	—	38.4	51.2	75.0	—	30	—
Fulgrain Strain 6	4205	—	42.7	52.6	—	—	47.5	61.0	77.9	—	58	—
Victorgrain Strain 4	4314	—	—	53.3	—	—	53.3	71.4	74.6	—	28	—
Quincy Red (Quincy 1)	4077	57.4	32.9	47.7	—	—	46.1	67.6	68.2	—	89	—
(Fulgh.-Mark.)×(Victoria-Rich.)	4319	—	—	18.4	—	—	18.4	71.4	25.8	—	28	—
Fulgrain Strain 7	4389	—	—	—	43.2	—	43.2	79.8	54.1	—	18	—
Victorgrain Strain 5	4388	—	—	—	52.7	50.3	51.2	72.8	70.3	—	50	—

TABLE 2.—*Concluded.*

Variety or selection	C. I. No.	1942 (31 stations)	1943 (30 stations)	1944 (28 stations)	1945 (18 stations)	1946 (32 stations)	Weighted average survival				Number of test	
							Variety	Winter Turf (same tests)	Percentage Winter Turf			
									1942–46	1926–46	1942–46	1926–46
Red Rustproof and Red Rustproof Hybrids												
Appler	1815	62.6	36.9	53.1	53.2	50.9	51.2	69.5	73.7	85.3	139	412
Rangler	3733	59.2	36.8	52.8	44.7	—	48.8	69.7	70.0	74.3	107	136
Carolina Red (T63)	4313	—	—	54.3	54.1	54.9	54.5	72.3	75.4	—	78	—
Ranger (Tex. M19–17)	3417	57.4	32.7	—	—	—	45.3	65.9	68.7	76.1	61	114
Rustler (Tex. M19–19)	3754	55.6	—	—	—	—	55.6	80.1	69.4	78.5	31	60
Red Rustproof × (Victoria-Richland)	3955	59.0	27.2	—	—	—	43.4	65.9	65.9	—	61	—
Nortex × Victoria (T 61)	3752	—	32.5	—	—	—	32.5	51.2	63.5	—	30	—
(Nortex-Victoria) × (Richland-Fulghum)	4095	—	34.0	36.8	—	—	35.4	61.0	58.0	—	58	—
Red Rustproof × (Victoria-Richland)	4385	—	—	—	47.4	45.4	46.1	72.8	63.3	—	50	—
Red Rustproof × (Victoria-Richland)	4386	—	—	—	47.7	42.3	44.2	72.8	60.7	—	50	—
Red Rustproof 2 × (Victoria-Richland)	4387	—	—	—	33.5	—	33.5	79.8	42.0	—	18	—
Red Rustproof 2 × (Victoria-Richland)	4384	—	—	—	36.2	—	36.2	79.8	45.4	—	18	—
Red Rustproof 2 × (Victoria-Richland)	4552	—	—	—	—	44.4	44.4	68.9	64.4	—	32	—
Red Rustproof 2 × (Victoria-Richland)	4553	—	—	—	—	52.7	52.7	68.9	76.5	—	32	—
Miscellaneous Hybrids												
Camellia (Bond × Alber)	4079	53.2	26.1	31.4	—	—	37.2	67.6	55.0	—	89	—
Victoria × Norton	4318	—	—	61.7	59.0	—	60.0	74.7	81.1	—	46	—
Radford (Winter Turf × Aurora)	4545	—	—	—	—	68.6	68.6	68.9	99.6	—	32	—
Bristol (Winter Turf × Culred)	4547	—	—	—	—	64.5	64.5	68.9	93.6	—	32	—
Boliver (Fulghum C.I. 2500 × Winter Turf)	4549	—	—	—	—	68.4	68.4	68.9	99.3	—	32	—
Woodward Strain	3527	—	—	79.2	—	—	79.2	71.4	110.9	104.6	28	81
Traveler (Custis × Victoria)	4206	—	—	—	—	62.5	62.5	68.9	90.7	—	32	—
Tenn. Fulghum Sel. 090 × Bond	4380	—	—	—	64.0	—	64.0	79.8	80.2	—	18	—

*Due to an error in the preparation of the seed in 1944–45, a much less hardy strain was substituted for Wintok in a portion of the nurseries, consequently all data on Wintok for 1944–45 are omitted.

plant and kernel characters. The general divisions are as follows: Black Winter, Culberson, Winter Turf, Lee, Fulghum, Red Rustproof, and miscellaneous hybrid strains several of which are still not entirely homozygous. Others might, with equal justification, assign certain of these entries to some other class than that to which they are assigned here. No attempt is being made at this time to classify oats. However, in a recent publication (4), it was indicated that probably Red Rustproof could be considered as representing a rather primitive oat type which gave rise to such types as Winter Turf, Culberson, Fulghum, and Black Winter, and still more recently to types such as Lee and its derivatives.

In general, Red Rustproof type oats have been the least hardy in these tests, whereas the Culberson type oats and certain Fulghum strains have been the most hardy. A strain of Winter Turf, possibly a derivative of red oats and formerly considered the most hardy oat variety grown in this country, was continued as the check variety in these tests.

Throughout the 5 years, 1942–46, Winter Turf strain (C.I. 3296)[4] gave an average survival of 69.5%. Reference to the data in Table 2 indicates that 9 entries grown one or more years during the period exceeded Winter Turf in hardiness. These were Tech, of the Black Winter group; Hairy Culberson, Bicknell, and Wintok of the Culberson group; C. I. 4207, a Fulghum (C. I. 2500)×Winter Turf 203–5 hybrid selection, classed as belonging to the Winter Turf group; C. I. 4204, a selection from the group of crosses of Fulwin×(Lee-Victoria); Woodward Strain; and the Fulghum derivatives, Fulghum (Winter Type, C. I. 2499), Fulwin, and Forkedeer.

Among strains grown for years other than those during the period 1942–46, nine exceeded the Winter Turf check in hardiness. These were the same entries in nearly all cases as those mentioned above. An exception is Pioneer, a Winter Turf type strain.

Among the most hardy varieties included in these nurseries, whether for the period 1942–46 or a longer period, are, in order, Wintok, Fulwin, Hairy Culberson, Bicknell, Forkedeer, Fulghum (winter type C. I. 2499), and Tech. No exceptionally hardy oat has been discovered during the 5-year period, 1942–46. All of the above were proved hardy in nurseries grown and reported on previously (1, 2, 3, 6).

DISCUSSION AND SUMMARY

Results from the uniform hardiness nurseries for the 5-year period, 1942–46, in general support results of the previous 15 years. In these nurseries, which have now been conducted for 20 years, the most hardy varieties grown in all tests have been Hairy Culberson, Bicknell, Fulghum (Winter type, C. I. 2499), and Tech. All have been more hardy than Winter Turf (C. I. 3296), the check variety, formerly considered the most hardy oat grown in this country. Other varieties grown in all tests are Lee, Fulghum (C. I. 708), and Appler. Lee has been somewhat less hardy than Winter Turf, whereas Fulghum (C. I.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

708) survived only 88.4% and Appler only to 85.3% as well as Winter Turf. As oats of the Red Rustproof and the Fulghum types are among the ones grown most widely from fall seeding, the need for greater hardiness in oats of these types is evident.

A marked increase in hardiness has been obtained by oat breeders during the past 20 years. Although Winter Turf was considered the most hardy oat grown previous to the beginning of these experiments in 1926, results obtained during the 20 years indicate that Wintok is 14.8% more hardy than Turf in 233 comparisons and that Fulwin has been 11.4% more hardy in 274 comparisons. Hairy Culberson and Bicknell have been 7.7 and 7.0%, respectively, more hardy in 411 and 412 comparisons.

Fulwin, Hairy Culberson, and Bicknell were selected from older varieties, whereas Wintok resulted from a cross of Hairy Culberson with a hardy selection from Fulghum (C. I. 2500). The added hardiness of Wintok indicates that further progress in breeding hardier oats may well be expected from crossing among present hardy varieties. Such progress, however, may be slow with little marked advance.

Progress made has not as yet been too spectacular in the attempt to combine disease resistance with hardiness in oats. Among the most hardy named oats tested which appear to be resistant to crown rust and smut are the Letoria, Stanton, and DeSoto varieties from the Lee×Victoria cross (7, 8, 10, 11). In 221 comparisons Letoria survived 99.9% as well as Winter Turf, whereas Stanton has survived 98.0% as well in 90 comparisons. Lee, the cold-resistant parent of these two varieties, averaged only 97.0% of Winter Turf in 412 comparisons. Consequently, in Letoria and Stanton have been combined cold resistance and disease resistance, indicating the possibility of further progress in combining known disease resistance with cold resistance.

Among selections derived from crosses of Fulghum and Red Rustproof, and their derivatives, a few strains have been obtained which are fully as hardy as the original Red Rustproof and Fulghum parents but no exceptionally hardy, disease-resistant oat of either type has been obtained. The most hardy disease-resistant Fulghum type oat yet tested has been Victorgrain (C. I. 3692). It has given a survival of 86.7% of Winter Turf check compared with the 88.4% of Winter Turf given by Fulghum (C. I. 708). Victorgrain was evolved from a cross between Victoria and Fulgrain of which the latter, in turn, originated as a Fulghum×Norton selection. Fultex (5,8,9,11) from the Fulghum×Victoria cross is nearly as hardy as Victorgrain.

Among the Red Rustproof derivatives Carolina Red evolved from the Nortex×Victoria cross (5,8,9,11) has been most hardy, having a survival of 75.4% of Winter Turf as compared with 73.7% for Appler. As Red Rustproof and Fulghum type oats remain among the most extensively grown oat types seeded in the fall, the need for obtaining hardier oats of these two types is evident.

Since the evidence indicates that all of the more hardy oats grown in America include certain red oats in their parentage, it would seem advisable to investigate red oats, including the wild red oat species as probable sources of additional genes for winterhardiness.

LITERATURE CITED

1. COFFMAN, FRANKLIN A. Species hybridization, a probable method for producing hardier winter oats. Jour. Amer. Soc. Agron., 29:79–81. 1937.
2. ————. The comparative winterhardiness of oat varieties. U. S. D. A. Cir. 622. 1941.
3. ————. Survival of oats grown in winter hardiness nurseries, 1937 to 1941. Jour. Amer. Soc. Agron., 34: 651–658. 1942.
4. ————. Origin of cultivated oats. Jour. Amer. Soc. Agron., 38: 983–1002, 1946.
5. ————. HUMPHREY, H. B., and MURPHY, H. C. New red oats for fall seeding resistant to rusts and smuts. Jour. Amer. Soc. Agron., 33: 872–882. 1941.
6. MURPHY, H. C. Effect of crown and stem rusts on the relative cold resistance of varieties and selections of oats. Phytopathology, 21:763–782. 1939.
7. ————, STANTON, T. R., and STEVENS, HARLAND. Breeding winter oats resistant to crown rust, smut, and cold. Jour. Amer. Soc. Agron., 18:622–637. 1937.
8. ————, ————, and COFFMAN, F. A. Breeding for disease resistance in oats. Jour. Amer. Soc. Agron., 34:72–89. 1942.
9. STANTON, T. R. Registration of varieties and strains of oats, X. Jour. Amer. Soc. Agron. 33:246–251. 1941.
10. ————. Registration of varieties and strains of oats, XII. Jour. Amer. Soc. Agron. 35:242–244. 1943.
11. ———— and COFFMAN, F. A. Disease resistant and hardy oats for the South. U. S. D. A. Farmers' Bul. 1947. 1943.

Agronomic Affairs

THE 1948 MEETINGS

THE 1948 meetings of the American Society of Agronomy and Soil Science Society of America have been set for August 24 to 27, 1948, at Fort Collins, Colorado, with Colorado A & M College as our host. The committee from Colorado consisting of H. E. Brewbaker, D. V. Robertson, P. B. Smith, and A. W. Skuderna which surveyed possibilities in the Colorado area were able to secure the most adequate accommodations for meetings and rooms at Fort Collins. The time and place have been approved by the Executive Committee of the Society. Plan a joint vacation and business trip to Colorado next August—it will be well worth the investment.

ABSTRACTS OF CEREALS AND CEREAL PRODUCTS

BEGINNING with January, 1948, *Biological Abstracts* will contain a new section, J—Abstracts of Cereals and Cereal Products. It will afford ready access to all the important literature of interest to millers, chemists, and research workers in cereals and other grains. It is being established in cooperation with the American Association of Cereal Chemists and the Millers' National Federation. Section J will bring together abstracts of the entire technological and scientific literature on the cereal grains—wheat, corn, rye, oats, and barley—and on all other grains such as soybean, cottonseed, buckwheat, etc., utilized by the milling and food industries. It will include contributions on plant breeding, cultural practices, varieties, soil and weather relations of the crops; physiology, diseases, insect pests; storage of

grain and flour; milling machinery and techniques; plant sanitation; baking and nutritional studies on diets in which cereal and related products are important components; biochemistry of cereals and cereal products; enzymes; and industrial microbiology in so far as it affects the cereals and their products.

Section J will be published monthly except during the four summer months when it will be published bi-monthly. A volume, coinciding with the calendar year, will consist of ten regular abstract issues, plus the comprehensive index issue of the complete edition of *Biological Abstracts*. The price will be $6.00 a year (foreign, $6.50).

SOIL SURVEYS IN THE CARIBBEAN

THE West Indies Conference, Second Session, which met in St. Thomas, Virgin Islands of the United States, February to March, 1946, considered among other matters the question of soil surveys in the Caribbean. Its recommendation to the Caribbean Commission is recorded in paragraphs 29–31 of the report of Committee III and is as follows:

"29. The number of qualified soil scientists in the Caribbean is extremely limited and a formal conference would at present be of little advantage. We suggest, however, that an early informal meeting in Puerto Rico would be of immediate practical benefit in order that nomenclature and methods may be standardized as far as possible for the purposes of a regional soil survey.

30. We accordingly recommend that the Caribbean Commission convene an informal meeting of soil scientists nominated by the governments of the Caribbean territories, together with soil scientists of the United States Department of Agriculture, in particular those who took an active part in the survey of Puerto Rico, and soil scientists from other metropolitan governments, should they wish to be represented. Such a meeting should take place in Puerto Rico at an early date.

31. We believe that the soil scientists attending this informal meeting may well consider and offer recommendations regarding the desirability of a formal conference at a later date for the purpose of developing a regional program of soil surveys."

With the object of obtaining advice on the recommendation, the Caribbean Commission, of which the West Indian Conference is an auxiliary body, recently appointed a sub-committee of soil scientists representative of French, Netherlands, British and United States territories of the Caribbean and comprising: H. J. Page, Principal of the Imperial College of Tropical Agriculture, Trinidad, chairman; D. Blanche, Acting Head of the Agricultural Service, Martinique; J. A. Bonnet, Head of the Soils Department, Agricultural Experiment Station of the University of Puerto Rico; F. Hardy, Professor of Chemistry and Soil Science, Imperial College of Tropical Agriculture, Trinidad; and H. J. Muller, Agricultural Chemist, Department of Agricultural Economics, Surinam.

The sub-committee met in Trinidad from March 15 to 18, 1947. Excursions were arranged by Professor Hardy to demonstrate typical soils in relation to local geological, lithological and topographical conditions and to local crops; and also in relation to soils elsewhere in the Caribbean region. The laboratory methods in use at the the Imperial College were also demonstrated.

The sub-committee recommended that a Conference of Soil Scientists should be held in Puerto Rico in 1948, under the auspices of the Committee on Agriculture, Nutrition, Fisheries and Forestry of the Caribbean Research Council, for the purpose of studying systems and methods of classification and mapping of tropical soils, with special reference to the standardization of such systems and methods for use in soil surveys throughout the Caribbean region and to carrying out such surveys as soon as possible. The proposed agenda is (a), presentation and discussion of collected data on soil forming factors of the various territories; (b) standardization of field and laboratory methods of soil surveys; (c) discussion of different systems of soil classification and mapping; (d) formulation of a detailed regional programme of soil surveys; (e) survey of problems of soil erosion, soil conservation and soil renovation in the different territories; and (f) practical application of soil surveys to land utilization.

The intention is that papers on these subjects should not be read but would be distributed to participants well in advance of the conference, at which they would be briefly introduced by the authors as a prelude to general discussion.

It was also recommended that attendance at the conference should be as representative as possible and should include soil scientists, who are specially interested in tropical soils from the above-mentioned points of view, not only from the Caribbean, but also from other countries. In this connection special reference was made to Cuba, Haiti, and the Dominican Republic and it was recommended that the governments of these countries should be invited to send representatives to participate in the conference.

The recommendations have since been approved by the Caribbean Commission and a working committeee has been set up to prepare for the conference, the date of which has not yet been definitely fixed.

CONFERENCE ON RADIOACTIVE ISOTOPES AS TRACERS IN AGRICULTURE

A NATION-WIDE conference on the use of radioactive isotopes in agricultural research is to be held December 18 to 20 at Alabama Polytechnic Institute, Auburn, Ala., in cooperation with the Oak Ridge Institute of Nuclear Studies.

The three-day meeting, which will include lectures by some of the country's foremost investigators in the field, will be the first to be held in the world on the application of radioactive materials to agricultural research. The first day of the conference will be concerned with fundamentals. The second day will be devoted to the use of radioactive materials to plant physiology, soils, and horticultural research, and laboratory demonstrations of typical tracer experiments. The conference will conclude with lectures on the use of radioactive materials in nutrition and animal husbandry fields.

Room and meal accommodations on the Alabama Polytechnic Institute campus have been arranged for the conferees.

WEED CONTROL CONFERENCE

THE annual meeting of the North Central Weed Control Conference will be held in Topeka, Kan., December 10, 11, and 12. A copy of the tentative program and information about hotel accomodations in Topeka may be obtained by writing to the President of the Conference, Moel S. Hanson, Department of Agronomy, University of Nebraska, Lincoln, Neb.

NEWS ITEMS

MISS WU, CHIH-HWA, Associate Professor of Agricultural Chemistry, University of Chekiang, Hangchow, Chekiang, China, who has been working on the spectrographic determination of zinc in soils at the University of Florida since March, 1946, received the Master of Science degree in July and has returned to China.

—A—

BEN L. MATZEK has been named Instructor in Agronomy in Crops and Soils at the North Dakota Agricultural College, Fargo, N. D. Mr. Matzek, a graduate of the North Dakota Agricultural College, has been connected with the Soil Survey Division of the Bureau of Plant Industry, Soils, and Agricultural Engineering in Tennessee for about ten years except for a period of post-graduate study at Cornell University.

—A—

A "BUTLER" type steel building with concrete floor, insulated, heated, and lighted, is being constructed at the North Dakota Agricultural College for a crops laboratory.

—A—

DOCTOR ENOCH B. NORUM, until recently in charge of Soil Fertility and Farm Management work for the Minnesota Valley Canning Company at St. Peter, Minn., has been named Associate Professor of Soils in the School of Agriculture and Associate Soil Scientist of the Experiment Station at Fargo, N. D.

—A—

WANTED TO PURCHASE—One copy of Volume 1 of the Proceedings of the Soil Science Society of America. Address Edwin Harrington, 1805 Fairmount Ave., Philadelphia 30, Pa.

Erratum

THE date of receipt of the paper by Etlar L. Nielsen in the September issue of the JOURNAL (pages 822–827) should have been June 2, 1947; not 1942. Also, in Table 2 (page 825) in this article in the first line under 1944 there should be a figure "1" under the heading "Dead".

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Inheritance of Seedcoat Color in Derivatives of Pinto Beans[1]

FRANCIS L. SMITH[2]

THE Pinto variety is the second most important variety of dry beans grown in the United States. It has a wide range of adaptation and is grown extensively in many of the western states.

Commercial samples of the variety usually contain a number of seedcoat color variants. In 1939, a sample consisting of 333 plants was taken at random from a commercial field of Pinto beans. Seed from each of these plants was grown in a progeny row in 1940. The color types found are shown in Table 1. In describing the seedcoat colors, the system used in the literature will be followed. The mottled bean colors are expressed as fractions, the color of the mottling being the numerator and the base color the denominator.

The Pinto bean has brown mottling over a buff background, designated as brown/buff. The mottling gene, *M*, was among the first genes to be described in beans. In earlier work, the author (5)[3] has shown that in Red Kidney beans the genes which determine the background color in mottled beans also produce the same color in self-colored beans in the absence of the mottling gene. One gene noted for this action was *Rk* which, in the absence of *M*, produced self-colored buff beans and in the presence of *M* the background was buff. The recessive allele of R*k* caused the seedcoats to be testaceous, the color of the Red Kidney beans. A gene was also found which modified the color of the mottled areas, but in the absence of *M* there was no effect on the self-colored types. Lamprecht (3) has shown that a gene for red seedcoat, *R*, is an allele of *M* and that striping is caused by a third allele M^{st}.

The array of color types in the Pinto variety offered an opportunity to study seedcoat color genes in this variety and relate them to the known genes. Therefore, pure-breeding lines of a number of them were established. Brown/buff (Pinto) and brown stripe/buff (Striped Pinto) were obtained from true-breeding progenies indicated in Table

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication July 28, 1947.

[2]Assistant Agronomist. The author wishes to acknowledge the able assistance of Dr. Catharine Becker Madsen in the classification of some of the more recent F_2 hybrids and in the preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 1052.

1 as 1a and 2. Brown/pink was found in 1939 and purified from the plant indicated in Table 1 as 3a. The self-colored types were found in 1940. Self-colored buff segregated from the brown/buff plant shown in Table 1 as 1b, and self-colored pink segregated from the brown/pink plant shown in Table 1 as 3b. The pink/pink biotype in which there is a dark pink mottling on a pink background was first obtained from a brown/pink progeny row which segregated for brown/pink, pink/pink, and self-colored pink. The hybrid parent which produced this progeny row is indicated in Table 1 as 3b. Green/buff was obtained as an F_2 segregated in the cross pink/pink×brown/buff. The varieties Sutter Pink (6) and Bayo (2) were also used in these studies. The hybridization experiments were begun in 1941. After harvest, the hybrid pods from each maternal plant were given a cross number. In the F_1 nursery each cross was planted in a single row, flanked on one side with a planting from the maternal plant and in the other with a planting from the paternal plant. Each F_1 plant was harvested separately and grown in a progeny row in the F_2 nursery. Seed from a plant from each of the parental rows was planted on each side of the hybrid rows. In this way the identity of each crosss and its parents was kept intact through the F_2 generation. The results were analyzed by the Chi square method of goodness of fit and the P values were taken Fisher's table of X^2 (1).

RESULTS

BUFF×BROWN/BUFF (PINTO)

Self-colored buff beans were first noted in 1940 in a progeny row from Pinto indicated as 1b in Table 1. The row was harvested in bulk and 17% of the beans were self-colored buff. The buff type bred true. The first generation of the cross buff×brown/buff (Pinto) was brown/buff. The segregation of the second generation for brown/buff and buff is given in Table 2, line 1. A good fit to a 3:1 ratio was obtained which indicates that buff and pinto differ in only one gene. This difference may be represented by the symbols *M* (mottled) and m (self-colored) (5).

TABLE 1.—*Color types found in a field of commercial Pinto beans.*

Color type	Number of plants	Percentage of population
1. Mottled, brown/buff or normal Pinto:		
a. True breeding	308	92.5
b. Segregating self-colored buff	1	0.3
c. Variable pattern segregating striped	2	0.6
2. Striped, brown stripe/buff	15	4.5
3. Mottled, brown/pink:		
a. True breeding	1	0.3
b. Segregating pink/pink and self-colored pink	1	0.3
4. Mottled, black/buff segregating	2	0.6
5. Self-colored brown segregating	2	0.6
6. White	1	0.3
Total	333	100.0

TABLE 2.—F_2 *monohybrid segregations in crosses of Pinto derivatives.*

Cross*	Genotype	F_1	Observed		Calculated 3:1		
			Dominant	Recessive	Dominant	Recessive	P
1. Buff × brown/buff (Pinto)	$m \times M$	19 brown/buff	534	181	536.25	178.75	.90–.80
2. Buff × brown stripe/buff	$m \times M^{st}$	18 brown stripe/buff	930	286	912.00	304.00	.30–.20
3. Brown/pink × brown/buff (Pinto)	$M\,rk \times M\,Rk$	11 brown/buff	571	186	567.75	189.25	.80–.70
4. Buff × Red Kidney	$Rk \times rk$	2 buff	115	35	112.50	37.50	.70–.50
5. Pink × buff	$rk \times Rk$	6 buff	337	116	339.75	113.25	.80–.70
6. Pink/pink × Sutter Pink	$M\,rk \times m\,rk$	3 pink/pink	41	23	48.00	16.00	.05–.02
7. Brown/buff (Pinto) × green/buff	$Br \times br$	20 brown/buff	510	166	507.00	169.00	.90–.80
8. Brown/buff (Pinto) × green/buff (Bayo)	$Br \times br$	7 brown/buff	296	116	309.00	103.00	.20–.10

*Line 1, four crosses, 41-064-066 and 41.068; line 2, three crosses, 44.142–.144; line 3, eight crosses, 42.061-068; line 4, one cross, 44.141; line 5, one cross, 44.140; line 6, one cross, 44.147; line 7, four crosses, 44.131–.134; line 8, one cross, 44.139.

TABLE 3.—F_2 *segregation from Pinto × Striped Pinto and reciprocal.*

Cross*	Genotype	F_1	Observed			Calculated 1:2:1			P
			Mottled	Intermediate	Striped	Mottled	Intermediate	Striped	
1. Brown/buff (Pinto) × brown stripe/buff (Striped Pinto)	$M \times M^{st}$	16 intermediate	311	477	312	275.00	550.00	275.00	Very low
2. Brown stripe/buff (Striped Pinto) × brown/buff (Pinto)	$M^{st} \times M$	27 intermediate	454	811	448	428.25	856.50	428.25	Very low
Total		43 intermediate	765	1,288	760	703.25	1,406.50	703.25	Very low

*Line 1, three crosses, 41.046–.048; line 2, 11 crosses, 41.072–.078 and 41.082–085.

BROWN/BUFF (PINTO) × BROWN STRIPE/BUFF (STRIPED PINTO)

In the sample taken in 1939, 15 plants, or 4.5%, of the population, had a striped pattern of brown/buff rather than the mottled pattern of the normal Pinto. These are shown as 2 in Table 1. Two progenies with a "variable" Pinto pattern proved heterozygous for the striped vs. mottled pattern. These are indicated in Table 1 as 1c.

Three crosses of Pinto × Striped and 11 of the reciprocal were made in 1941. All the F_1 plants in these crosses were intermediate between striped and mottled Pinto. The segregation in the F_2 generation is given in Table 3. There is a deficit of the intermediate class. This may have been caused by misclassification of the intermediates, which are difficult to distinguish, into the two parental groups. The two parental classes were almost exactly equal. In spite of the poor fit to a 1:2:1 ratio, the action of a single gene seems likely. This relationship may be expressed by the M (mottled) and M^{st} (striped) (3). The results obtained in these crosses are in conformance with this hypothesis, with the exception that the heterozygous $M\ M^{st}$ class was lower than expected.

BUFF × BROWN STRIPE/BUFF (STRIPED PINTO)

The preceding results indicate that the stripe pattern may differ from mottled Pinto pattern by one gene pair, $M\ M^{st}$. Likewise the self-colored buff is supposedly the result of a mutation of M to m. Three crosses of buff × brown stripe/buff (Striped Pinto) were made and progenies from 18 F_1 striped plants were grown. The F_2 generation segregated brown striped/buff and buff in a 3:1 ration. The results, shown in Table 2, line 2, fit a monohybrid ration, indicating the M^{st} is an allele of m. Therefore M, M^{st}, and m form an allelomorphic series.

BROWN/PINK × BROWN/BUFF (PINTO)

In the original field sample there were two mottled plants that were brown/pink rather than brown/buff. One of these bred true as shown in Table 1, 3a. When this plant was crossed with brown/buff (Pinto), the 11 F_1 plants were brown/buff, and the segregation of the F_2 generation was brown/buff and brown/pink. The results, shown in Table 2, line 3, fit a monohybrid ratio with a P value between .80 and .70. The gene pair determining buff vs. pink ground color may be represented by the symbols Rk and rk.

PINK FROM BROWN/PINK

The progeny row grown from the one brown/pink plant indicated as 3b in Table 1 was harvested in bulk, and segregated 58% brown/pink, 26% pink/pink, and 16% self-colored pink beans. More recently three segregating progenies of brown/pink have given brown/pink and pink in the ratio of 93:23. Fitted to a 3:1 ratio the probability value lies between .30 and .20. Thus, the self-colored pink has the same relation to brown/pink as the self-colored buff has to brown/buff. In both cases the mottling gene M has mutated to m. The buff may be represented by $m\ Rk$ and the pink by $m\ rk$.

RED KIDNEY × PINK

In an earlier study the author (5) has shown that the gene for testaceous color of Red Kidney, *rk*, has a dominant allele, *Rk*, which makes the seedcoat color buff. In the cross Red Kidney × Pink the F_2 color segregation was so slight that no color classes could be made. It may be assumed that the pink color of Pink beans is caused mainly by the same *rk* gene which causes the testaceous color in Red Kidney. The color difference between these two varieties then is due to slight color modifying genes.

BUFF × RED KIDNEY

The buff derivative from Pinto was crossed with Red Kidney, producing two buff F_1 plants. The F_2 segregated buff and testaceous in a monohybrid ratio as shown in Table 2, line 4. This buff may therefore be designated as *Rk*.

PINK × BUFF

As in the cross Buff × Red Kidney discussed above, the F_1 from Pink × Buff was buff, and the F_2 segregated buff and pink in monohybrid ratio as shown in Table 2, line 5. Thus, the *Rk* gene of buff is an allele of both the Red Kidney testaceous *rk* and the Pink *rk* genes. The only difference between the results from this cross and the brown/pink × brown/buff cross (Table 2, line 3) is the effect of the *M* gene for mottling. The ground color in mottled beans is determined by the same genes that determine the seedcoat color in self-colored beans. The buff color may be represented by *Rk* and the pink as *rk*. When *M*, the gene for mottling, is present, the *Rk* genotypes have a buff background and the *rk* genotypes have a pink background.

PINK/PINK × SUTTER PINK

The pink/pink derivative noted in Table 1, 3b, segregated from a brown/pink plant selection. It was crossed with Sutter Pink (6). The three F_1 plants were pink/pink and the F_2 segregated pink/pink and pink in monohybrid ratio, as shown in Table 2, line 6. The P value was low, between .05 and .02, because of an excessive number of pink segregates, but the size of the segregating population was small. The gene pair segregating in this cross is *M m*. The pink derivatives from Pinto then have the same *rk* gene that is responsible for this color in the Sutter Pink variety.

PINK/PINK × BROWN/BUFF (PINTO)

This cross should segregate for the *Rk rk* gene pair since the background color in one case is buff and the other is pink. The color of the F_1 plants was brown/buff. The F_2 results are shown in Table 4, line 1. A new color type was observed—green/buff. The green/buff phenotype must be caused by a modifying factor which acts only in the presence of the mottling gene *M*. When *Rk* is present, this modifying gene, which is designated as *Br* (for brown), produces brown/buff mottled beans. In the presence of *br*, however, the mottling is changed from brown to green. A similar situation exists in beans carrying *rk*.

TABLE 4.—F_2 *dihybrid segregation for the Rk and Br genes in crosses of Pinto derivatives.**

Genotype	F_1	Brown/buff *Rk Br*	Green/buff *Rk br*	Brown/pink *rk Br*	Pink/pink *rk br*	P
		1. Pink/pink×brown/buff				
rk br×*Rk Br*	23 brown/buff	1,063	290	469		
Calculated for 9:3:4 ratio		1,024.88	341.62	455.50		Very low
Calculated for 37.6% linkage		1,088.78	277.72	455.50		.50–.30
		2. Pink×brown/buff				
rk br×*Rk Br*	20 brown/buff	504	121	184		
Calculated for 9:3:4 ratio		455.06	151.69	202.25		Very low
Calculated for 37.6% linkage		483.44	123.31	202.25		.30–.20
		3. Brown stripe/buff×Sutter Pink				
Rk Br×*rk br*	9 brown stripe/buff	246	70	105		
Calculated for 9:3:4 ratio		236.81	78.94	105.25		.50
Calculated for 37.6% linkage		251.58	64.17	105.25		.80–.70
		4. Pink/pink×brown stripe/buff				
rk br×*Rk Br*	8 brown/buff	171	40	44	30	
Calculated for 9:3:3:1 ratio		160.31	53.44	53.44	17.81	Very low
Calculated for 37.6% linkage		170.31	43.44	43.44	27.81	.95–.90
		5. Pink/pink×buff				
rk br×*Rk Br*	4 brown/buff	185	37	60.		
Calculated for 9:3:4 ratio		158.63	52.87	70.50		Very low
Calculated for 37.6% linkage		168.52	42.98	70.50		.20–.10
		Total				
Observed		2,169	558	892		
Calculated for 9:3:4 ratio		2,035.69	678.56	904.75		Very low
Calculated for 37.6% linkage		2,162.63	551.62	904.75		.90–.80

*Line 1, 10 crosses, 41.049, 41.051, 41.052, 41.055, 41.056 and 41.069–.073; line 2, three crosses, 41.059, 41.061, and 41.062; line 3, one cross, 41.125; line 4, two crosses, 44.136 and 44.137; line 5, one cross, 44.145.

The *M rk Br* genotype is brown/pink and the *M rk br* is pink/pink. Unfortunately, a knowledge of these nuances took some time to learn. In the cross reported in Table 4, line 1, the pink/pink genotypes were not distinguished from the brown/pink, therefore both types were classed together.

This cross illustrated another anomaly. When fitted to a 9:3:4 ratio, the probability value is very low. The poor fit results from the fact that the *Rk Br* class is higher and the *Rk br* class is lower than expected on the assumption of independent assortment of the *Rk* and *Br* genes. The excess parental types and the paucity of nonparental combinations may be due to linkage of *Rk* and *Br*. If there is linkage, the *Rk br* class would be the crossover class and would be low and the *Rk Br* class would be the noncrossover class and would be high because *Rk* and *Br* came into the cross in a coupling phase.

All the crosses involving the interactions of the *Rk* and *Br* genes were tabulated together in Table 4. On the assumption of independent assortment the composite data gave a very poor fit to the expected 9:3:4 ratio. The deviations from the expected di-hybrid ratio were calculated and the average deviation was obtained from which the linkage value of 37.6% was calculated. In each of these crosses the P values are given for independent assortment of *Rk* and *Br* and for linkage of 37.6% between these two genes. In every case the probability value is improved if linkage of this order is assumed.

From this cross then, evidence was obtained for the presence of a gene, *Br*, modifying the color of the mottled areas. This explains the appearance of the green/buff biotype. Furthermore, the *Br* gene is loosely linked with the *Rk* gene.

PINK×BROWN/BUFF (PINTO)

Crosses of pink×brown/buff (Pinto) yielded two different types of progenies. In the first type, shown in Table 5, line 1, segregation was expected for the genes *M* and *Rk*. The fit to a di-hybrid ratio is low because of an excess of the brown/buff, *M Rk Br* phenotype. The pink parents used in these crosses must have carried *Br* because the Pinto variety is known to carry *Br* and there was no segregation for this gene.

In the other type of pink×brown/buff (Pinto) cross, the green/buff color appeared. The results are shown in Table 6, line 1. The segregating genes are *M*, *Rk*, and *Br*. Evidently the pink parents used in these crosses carried the *br* gene. The fit to a theoretical trihybrid ratio calculated on the basis of independent assortment is very low, due to a high proportion of brown/buff types. There were 809 mottled *M* to 245 self-colored *m*, which fits a 3:1 ratio with a P value of .20–.10. There were 791 buff *Rk* to 263 pink *rk*, a nearly perfect fit to a 3:1 ratio. The P value is between .98 and .95. At least these two genes were segregating normally. Since the difference between *Br*. and *br* can be ascertained only in the presence of *M*, the mottled beans were separately analyzed for *Rk* and *Br* in Table 4, line 2. The fit to a 9:3:4 ratio was very low, but when a linkage of 37.6% was assumed, the P value was between .30 and .20.

TABLE 5.—*F_2 dihybrid segregation in crosses of Pinto derivatives involving the gene M with Rk or Br.**

Genotype	F_1	F_2 genotype and color				P
		1. Pink×brown/buff (Pinto)				
		Brown/buff *M Rk Br*	Brown/pink *M rk Br*	Buff *m Rk*	Pink *m rk*	
Observed *m rk Br×M Rk Br*	13 brown/buff	288	80	64	23	
Calculated for 9:3:3:1 ratio		255.94	85.31	85.31	28.44	.02–.01
		2. Green/buff×Sutter Pink				
		Green/buff *M Rk br*	Pink/pink *M rk br*	Buff *m Rk*	Pink *m rk*	
Observed *M Rk br×m rk br*	3 green/buff	82	21	25	4	
Calculated for 9:3:3:1 ratio		74.25	24.75	24.75	8.25	.50–.30
		3. Green/buff×buff				
		Brown/buff *M Rk Br*	Green/buff *M Rk br*	Buff *m Rk*		
Observed *M Rk br×m Rk Br*	5 brown/buff	194	57	111	—	
Calculated for 9:3:4 ratio		203.62	67.88	90.50	—	.05–.02

*Line 1, three crosses, 41.059, 41.061, and 41.062; line 2, one cross, 44.148; line 3, one cross, 44.146.

BROWN STRIPE/BUFF (STRIPED PINTO) × SUTTER PINK

The Striped Pinto pattern was shown in the crosses with Pinto and with buff to be governed by M^{st} *Rk* and presumably *Br*. (Table 3) The Sutter Pink variety was shown in a cross with pink/pink to carry *m rk* (Table 2, line 6). It may also carry either *Br* or *br*. The F_1 of the cross Striped Pinto × Sutter Pink was brown stripe/buff. The segregation in the F_2 generation is presented in Table 6, line 2. These results fit fairly closely to a modified trihybrid ratio. The three genes segregating in this case were M^{st}, *Br*, and *Rk*. In the self-colored types, *m Rk Br* and *m Rk br* are buff, while *m rk Br* and *m rk br* are pink. No evidence of linkage between M^{st} and *Br* is apparent. The fit to the expected ratio, assuming independent assortment, is within the realm of probability being between .30 and .20. However, it should be noted that the nonparental combinations are lower than expected and the parental combination are higher where *Rk* and *Br* genes are concerned. Considering only the mottled beans, because *Br* cannot be detected in the presence of *m*, the observations were fitted to an assumption of 37.6% linkage in Table 4, line 3. The phenotypic classes showed less deviation from expectation and the P value was improved from .50 to between .80 and .70. This lends further support to the hypothesis of linkage between the *Rk* and *Br* genes.

PINK/PINK × BROWN STRIPE/BUFF (STRIPED PINTO)

In this cross, segregation for M M^{st}, *Br br*, and *Rk rk* is expected. Since the heterozygote M M^{st} is intermediate, the F_2 segregation should be 1 striped:2 intermediate:1 mottled. Since *Br* and *br* are segregating, green/buff and pink/pink types should appear, as well as the brown/buff and brown/pink. If all the phenotypes were distinguishable, the following color types should appear in striped, intermediate, and mottled classes: brown/buff, green/buff, brown/pink, and pink/pink. However, in the color classes green/buff and pink/pink the color markings of the mottled areas were so faint that no attempt was made to differentiate striped, intermediate, and mottled types. Therefore, the green/buff and pink/pink were classified only as mottled. The F_2 results are given in Table 7. They are fitted to a modified trihybrid ratio and the P value is low, between .02 and .01. Considering the segregation of M^{st} in the brown/buff and brown/pink phenotypes only, 55 were striped, 99 were intermediate, and 61 were mottled. The calculated numbers for a 1:2:1 ratio are 53.75:107.50:53.75. The observed ratio fits the expected with a P value of between .50 and .30. The segregation of *Rk*:*rk* was 211:74 which fits the calculated ratio of 213.75:71.25 with a P value between .80 and .70. The segregation for the *Br br* gene in this case was 215:70. This fits the expected 3:1 ratio with a P value between .90 and .80. Thus, treated independently, segregations for all three genes fit expectation very closely. To test for linkage of *Rk* with *Br*, the F_2 classes were regrouped in Table 4, line 4. On the assumption of independent assortment a very poor fit was obtained, but the assumption of 37.6% linkage gave an excellent fit with a P value between .95 and .90.

TABLE 6.—*Trihybrid segregation for M, Rk, and Br in crosses of Pinto derivatives.**

Genotype	F_1	Brown/buff *M Rk Br*	Green/buff *M Rk br*	Brown/pink *M rk Br*	Pink/pink *M rk br*	Buff *m Rk*	Pink *m rk*	P
		1. Pink×brown/buff (Pinto)						
Observed *m rk br* × *M Rk Br*	20 brown/buff	504	121	184		166	79	
Calculated for 27:9:12:12:4 ratio		444.66	148.22	197.62		197.62	65.88	Very low
		2. Brown stripe/buff×Sutter Pink						
Observed M^{st} *Rk Br* × *m rk br*	9 brown stripe/buff	246	70	71	34	116	30	
Calculated for 27:9:9:3:12:4		239.20	79.74	79.74	26.57	106.31	35.44	.30–.20
		3. Pink/pink×buff						
Observed *M rk br* × *m Rk Br*	4 brown/buff	185	37	45	15	77	26	
Calculated for 27:9:9:3:12:4		162.42	54.14	54.14	18.05	72.19	24.06	.05–.02

*Line 1, six crosses, 41.050, 41.053, 41.054, 41.057, 41.058 and 41.060; line 2, one cross, 44.125; line 3, one cross, 44.145.

TABLE 7.—*Trihybrid segregation for M* M^{st} *Rk rk Br br in a cross of pink/pink×brown-stripe/buff (Striped Pinto).**

	Brown/buff			Brown/pink			Green/buff	Pink/pink	P
	Striped	Intermediate	Mottled	Striped	Intermediate	Mottled			
Observed	40	81	50	15	18	11	40	30	
Calculated for a 9:18:9:3:6:3:12:4 ratio	40.08	80.15	40.08	13.35	26.72	13.36	53.44	17.81	.02–.01

*Two crosses, 44.136 and 44.137. Eight intermediate brown/buff F_1 plants.

PINK/PINK×BUFF

In this cross segregation was expected for *M* and *Rk*. The F_1 plants were brown/buff. The buff parent must have carried *Br*, otherwise the F_1 would have been green/buff. The F_2 results are shown in Table 6, line 3. Segregation for three genes is evident. However, the fit is rather poor. The segregation for *M m* was 282:103 which fits the theoretical 3:1 ratio with a P value between .20 and .30. The segregation for *Rk rk* was 299:86, giving a P value between .30 and .20. The segregation for *Br br* noted only in the mottled beans was 230:52 which gives a low P value between .02 and .01. This poor fit may be partly caused by the difficulty of distinguishing between the brown/pink and the pink/pink color classes. The *M* and *Rk* genes segregate in a 9:3:3:1: ratio giving 222 *M Rk*:60 *M rk*:77 *m Rk*:26 *m rk*, with the P value lying between .50 and .30. The *Rk* and *Br* genes, however, do not segregate independently, as is shown in Table 4, line 5. The value of P when the data are fitted to a 9:3:3:1 ratio is between .02 and .01. When fitted to a 9:3:4 ratio, the P value is very low. Assuming linkage of 37.6%, the fit is better, giving a P value between .20 to .10, which offers further evidence of linkage of these two genes.

GREEN/BUFF×BUFF

This cross was made to study the difference between the green/buff and the self-colored buff. The cross was expected to segregate for *M m*. The F_1 was brown/buff giving evidence that the buff parent carried *Br* as well as *m*. The green/buff parent carried *M br*. The F_2 results are shown in Table 5, line 3. A 9:3:4 ratio gave a rather poor fit for independent assortment, the value of P being between .05 and .02. There was an excess of buff and a deficiency of green/buff. This was probably a result of the difficulties in classification, since the green mottling is faint and may be unobserved.

GREEN/BUFF×SUTTER PINK

On the basis of results shown in Tables 2 and 4, the Sutter Pink carries the genes *m rk br*. Green/buff is *M Rk br*; therefore, we should expect segregation in a cross between them for *M m* and *Rk rk* only. The results shown in Table 5, line 2, are in conformity with this hypothesis. The P value is between .50 and .30.

BROWN/BUFF (PINTO)×GREEN/BUFF

The F_1 of the crosses reported in Table 2, line 7, were brown/buff. The only gene segregating was *Br br* with a high P value between .90 and .80. This fact substantiates the hypothesis made to explain the results in Table 5 and 6 that *Br* acts in the presence of *M* or M^{st} to make the mottling or striping brown colored.

BROWN/BUFF (PINTO)×GREEN/BUFF (BAYO)

There is an old California bean variety known as Bayo (2). It has a buff-colored seedcoat which, upon close examination, shows green mottling. The beans are larger and rounder than the Pinto, but the

color markings are identical to the green/buff biotype isolated from the Pinto crosses. In order to test the Bayo color genetically, it was crossed with Pinto. The results of the cross are shown in Table 2, line 8. The segregation was similar to that obtained in Table 2, line 7. The Bayo then is assumed to carry *M br Rk*.

GREEN/BUFF (BAYO) × GREEN/BUFF

This cross (No. 44.139) was made to test whether the two color types were genetically identical. Four F_1 plants were obtained which were green/buff. The F_2 consisted of 69 green/buff plants. Thus, both green/buff types have the same genetic constitution for seed coat color.

PINK AND RED KIDNEY × GREAT NORTHERN

The white-seeded variety, Great Northern, is grown in the western states, especially in Idaho. The seed size and shape are much like Pinto. An Idaho mosaic-resistant strain (4) was used in crosses with Pink and Red Kidney in a breeding program for mosaic resistance. In both crosses the F_1 plants were brown/buff and looked like Pinto. The color segregation of the F_2 was not followed. Since these hybrids were inoculated with the mosaic virus and the susceptible plants were discarded, a complete population was not available. Both the Pink and Red Kidney varieties carry *rk* and *m* but may or may not carry *Br*. The color of the F_1 was due to the action of *M Rk* and *Br*. Therefore, at least *M* and *Rk* must have entered the cross from the Great Northern parent. It is conceivable that Great Northern may have arisen from Pinto through a mutation of the primary pigmentation factor *P* to the recessive *p*. The presence of *p* has been shown (5) to cause white beans regardless of any other seedcoat color genes the plant may have.

DISCUSSION

Some of the seedcoat color types extracted from Pinto are genotypically similar to some of the varieties grown in the West for dry beans. These similarities may give some indication of the origin of these varieties. If we assume that the mottled Pinto was a prototype, these varieties can be duplicated, as far as seedcoat color is concerned, by a series of mutations of a very few genes.

The Striped Pinto has been shown to carry an M^{st} allele of the mottling gene, *M*. By a mutation of *M* to M^{st} the striped pattern could have arisen and been easily perpetuated. This pattern is often seen in commercial samples of Pinto beans.

The Bayo bean is an old California variety which came into the state from Chile about a century ago (2). The present variety differs in many respects from the Pinto, but a green/buff Pinto derivative seems to be identical to the Bayo variety so far as seedcoat color genes are concerned. Thus, Bayo could have arisen by a mutation of the brown modifying gene *Br*. to *br*. This would change brown/buff to green/buff.

The Pink variety is widely grown in California. Its derivation from Pinto could occur by two gene mutations. The Pinto can be repre-

sented by *M Rk Br*. *Br* does not affect self-colored beans so changes in it would not be important. By two mutations, *M* to *m* and *Rk* to *rk*, a self-colored pink could occur. This type has been found in the Pinto derivatives. The order of the mutation would not affect the final product. If the *M* gene mutated first, the mutant type would be buff *m Rk*. If *Rk* should then mutate to *rk*, the pink type would occur. If *Rk* mutated first, the product would be brown/pink. A mutation of *M* to *m* would then produce self-colored pink. In these experiments the pink derivative from Pinto arose in the succession brown/buff to brown/pink to pink.

The Great Northern, a white seeded variety grown widely in Idaho has some of the same color genes as Pinto. It could have arisen from Pinto by a mutation of the primary pigmentation factor *P* to *p* (5). The white mutant then would carry the other genes intact. They would not affect the variety and could only be detected in crosses where the dominant *P* was introduced.

Thus, the dominant alleles carried in the Pinto variety could produce through mutation at least four commercial varieties. Mutant forms were found in derivatives from Pinto which duplicate the seed color types of these old and established varieties.

The genetic constitution for seedcoat colors in the western dry bean varieties may be represented as follows:

Pinto, *P M Rk Br*
Striped Pinto, *P* M^{st} *Rk Br*
Pink, *P m rk Br* or *P m rk br*
Bayo, *P M Rk br*
Red Kidney, *P m rk Br* or *P m rk br*
Great Northern, *p M Rk Br*

SUMMARY

A number of seedcoat color variants were found in the Pinto variety of beans. These derivatives have been subjected to a genetic analysis for seedcoat color. Most of the variations can be explained by assuming interactions of three genes, *M*, *Rk*, and *Br*, which are all present in the dorminant form in normal Pinto beans. *M*, a gene for mottling, has two allels, M^{st} for striped distribution of the mottling and *m* for self-colored beans. *Br* is a color modifier of the mottling. In the presence of *m*, the *Br* gene has no effect, in beans of the constitution *M Br* the mottling is brown, while in *M br* the mottling is green or pink in color. *Rk* is a color gene, affecting the ground color of mottled beans or the seed coat color of self colored beans. *Rk* produces buff color, while the recessive *rk* produces pink color. Beans of the constitution *M Rk Br* are brown/buff; *M Rk br*, green/buff, *M rk Br* brown/pink, and *M rk br* pink/pink. There is some linkage between the *Rk* and *Br* loci, the value calculated from all the available material being 37.6%.

There is a striking similarity between some of the Pinto derivative and other commerical varieties of western dry beans. These similarities of seedcoat color have been studied genetically. At least four commercial varieties could have arisen by a few mutations from the

Pinto prototype. These may be represented by the following slight differences in genetic constitution:

Pinto, *P M Rk Br*
Striped Pinto, *P M^{st} Rk Br*
Pink, *P m rk Br* or *P m rk br*
Bayo, *P M Rk br*
Red Kidney, *P m rk Br* or *P m rk br*
Great Northern, *p M Rk Br*

Other color biotypes found in the Pinto derivatives and tested genetically were:

Green/buff, *M Rk br*, similar to Bayo
Pink/pink, *M rk br*
Brown/pink, *M rk Br*.
Buff, *m Rk*
Pink, *m rk*, similar to Pink

LITERATURE CITED

1. FISHER, R. A. Statistical methods for Research Workers. Edinburgh: Oliver and Boyd. Ed. 2. 1928.
2. HENDRY, G. W. Bean culture in California. Calif. Agr. Exp. Sta. Bul. 294. 1921.
3. LAMPRECHT, H. Zur Genetick von Phaseolus vulgaris. XV. Uber die Vererbund der Mehrfabikeit die Testa. Hereditas, 26:65–99. 1940.
4. PIERCE, W. H. Resistance to common bean mosaic in the Great Northern field bean. Jour. Agr. Res., 49:183–188. 1934.
5. SMITH, F. L. A genetic analysis of red seed coat color in *Phaseolus vulgarus*. Hilgardia, 12:531–616. 1939.
6. ————. Sutter Pink beans in California. Calif. Agr. Exp. Sta. litho. 1944.

Response of Irish Potatoes to Phosphorus and Potassium on Soils Having Different Levels of These Nutrients in Maine and North Carolina[1]

W. L. Nelson and Arthur Hawkins[2]

In 1944 a study was initiated to determine the nutrient status of the soils in certain of the commerical Irish potato-producing areas. This study was cooperative between the Division of Soils, Fertilizers, and Irrigation, U. S. Dept. of Agriculture, and seven states along the Atlantic and Gulf Coasts. A very marked accumulation of soluble phosphorus and exchangeable potassium was reported, with the accumulation varying with the chemical characteristics of the soils and with the number of years the field had been planted to potatoes and fertilized heavily (6)[3].

The objective of the investigation reported in this paper is to show the relationship between the amounts of readily soluble phosphorus and exchangeable potassium in the soil and the response of Irish potatoes to applications of these two nutrients. Data from Maine and North Carolina are reported.

REVIEW OF LITERATURE

Large quantities of fertilizer are usually applied for Irish potatoes. Data obtained in 1940 and 1941 indicate that approximately 100 pounds of N, 185 pounds of P_2O_5, and 225 pounds of K_2O were applied per acre on potatoes in Aroostook County, Maine (9, 10). Since then, most of the growers have increased the rate of application of these nutrients. In North Carolina the usual per acre application is 120 pounds of N, 160 pounds of P_2O_5 and 120 pounds K_2O.

Under Maine conditions potatoes fertilized at the rate of 3,000 pounds of 4–8–8 per acre contained the following amounts in pounds per acre of nutrient elements in the plants, tubers included (average of four varieties): Nitrogen, 113 to 151 pounds N, phosphorus, 23 to 28 pounds P_2O_5, and potassium 188 to 253 pounds K_2O (7). It was found that the 232 hundredweights per acre yield of tubers of the Green Mountain variety contained approximately 95 pounds of N, 20 pounds of P_2O_5, and 117 pounds of K_2O. The differences between the amounts of nutrients applied and the amounts actually removed in the tubers indicate that a considerable accumulation of P_2O_5 and K_2O, particularly P_2O_5, might be expected in soils planted frequently to potatoes and fertilized heavily.

Chucka, *et al.* (5) found 80 pounds of P_2O_5 in the fertilizer to be sufficient for the Green Mountain variety grown on Caribou loam. Bushnell (3) suggested that when a soil contains over 200 p.p.m. of readily soluble phosphorus (Truog method)

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[3]Figures in parenthesis refer to "Literature Cited", p. 1066.

40 pounds P_2O_5 per acre in the fertilizer is sufficient. Brown (1) found no increase from applications of P_2O_5 on a soil containing 276 pounds of readily soluble phosphorus. The experiment was conducted for 5 years. Unpublished data for 1942 in North Carolina showed that an application of 160 pounds of P_2O_5 per acre as compared with 60 pounds resulted in increased yields of 11, 16, and 6 hundredweights per acre on soils containing 250, 287, and 288 p.p.m. of readily soluble phosphorus (Truog method), respectively. Results from Virginia (4) on a soil relatively low in fertility show a yield response to increasing amounts up to 240 pounds of P_2O_5 per acre. Ware (11) reports the need of 240 pounds P_2O_5 per acre on a Norfolk sandy loam. The soil contained 66 p.p.m. available phosphorus when 240 pounds of P_2O_5 had been applied 8 years and 5 ppm where none was applied.

There has been little attempt to relate the response from applied potash to the amount of exchangeable potassium in the soil. Early investigations in North Carolina revealed that 100 to 120 pounds per acre of K_2O in the fertilizer was adequate (12). These results were not related to soil analyses, however. Unpublished data in 1942 revealed that increasing amounts of K_2O up to 180 pounds per acre increased yields on soils containing 0.6 and 0.3 m.e. of exchangeable potassium.

In connection with the cooperative soils study initiated in 1944, field experiments were conducted in 1945 in Aroostook County and in North Carolina to determine the effect of rates of phosphorus applied to Irish potatoes grown on soils having a wide range of readily soluble phosphorus (6). A preliminary report of these experiments indicated that the increase in yield of potatoes per pound of P_2O_5 applied was usually lower at locations where there were high amounts of residual phosphorus in the soils. In addition, in Maine, field experiments with rates of potash applied to potatoes were conducted on soils having a wide range of exchangeable potassium. On soils having less than about 0.5 m.e. of exchangeable potassium per 100 grams of soil increases in yield above the 100-pound base rate of K_2O were obtained with 150 and 200 pounds of applied K_2O. However, these increases were not statistically significant. On soils containing more than 0.5 m.e. of exchangeable potassium little or no increase in yield occurred with applications greater than the 100-pound base rate. The general low response may have been due to the unfavorable growing season. The experiments reported in this paper are essentially a follow-up of the 1945 experiments.

MATERIALS AND METHODS

PHOSPHORUS RATE EXPERIMENTS

North Carolina.—Rate of phosphorus experiments were conducted at six locations in 1945 and 1946. The experiments were set up on soils containing from 48 to 850 pounds of readily soluble phosphorus (P_2O_5) per acre. In five of the experiments, conducted in Richland township of Beaufort County, five rates of P_2O_5 were applied, namely, 0, 40, 80, 120 and 160 pounds per acre. A 5×5 Latin square design was used. At the Tidewater Station in Washington County the content of readily soluble phosphorus was very low and two additional rates, 240 and 320 pounds of P_2O_5 per acre, were added. Four replications in a randomized block design were used. At all locations each of the treatments appeared on the same plots in 1945 and in 1946.

The plot size was 1/65 acre. Six-row plots 21×32 feet were used at the first five locations and six-row plots 18×37.3 feet at the Tidewater Station. At harvest 2 feet were discarded at each end of each plot before yields were taken.

Treble superphosphate was used as the source of P_2O_5. The amount of calcium applied with each treatment was kept constant by adding enough gypsum to equal the difference in the calcium of the mixture and that contained in the high phosphate mixture. In 1945 a uniform application of 100 pounds of nitrogen and 160 pounds of potash was applied, while in 1946, 120 pounds of nitrogen and 160 pounds of K_2O (200 pounds of K_2O per acre at the Tidewater Station) were applied to all plots. The fertilizer was formulated neutral with dolomitic limestone. The fertilizer was applied by hand along each side of the furrow and than covered so that it was 3 to 4 inches below the seed pieces. The Irish Cobbler variety was planted in all experiments.

Leaf samples were taken for analyses and were composed of 40 terminal leaflets from midway up the plant. Twenty leaflets were taken from a given treatment in replication 1 and in replication 2 and combined to make one sample. Replications 4 and 5 were likewise combined. In 1945 the leaf samples were taken at late bloom stage on May 10. In 1946 the sampling was made at the pre-bloom stage on April 24. Total phosphorus was determined in the ashed plant material.

The effect of applications of phosphorus on the number of tubers per hill and individual tuber weight was determined by sampling the tubers from one two-row section of each plot. The specific gravity was determined on No. 1 tubers by immersing in a series of NaCl solutions.

Soil analyses were made on individual samples composed of a trowelful from 16 sites (Table 1). The value given is an average of 10 individual samples. Readily soluble phosphorus was determined by the modified Truog method (6) and the exchangeable cations were determined by the ammonium acetate procedure.[4]

TABLE 1.—*Analyses of soil in North Carolina experiments.**

Location and soil type	pH	M.e. per 100 grams			K_2O, lbs. per acre	Millimols per 100 grams		P_2O_5 Truog, lbs. per acre	Organic matter, %
		Base ex. cap.	Ca	Mg		Anion ex. cap.	Ex. P		
Tidewater Station, Bladen silt loam..	5.2	16.8	3.0	0.61	169	4.5	0.4	48	7.9
R. S. Thompson, Portsmouth sandy loam............	4.7	16.6	4.1	0.86	423	2.8	0.9	310	8.2
H. M. Lewis, Portsmouth fine sandy loam............	4.6	19.3	4.3	0.69	301	4.3	1.3	410	9.4
I. W. Holadia, Portsmouth loam......	5.0	19.5	7.5	0.68	451	4.4	1.6	710	10.0
M. F. Thompson, Lynchburg sandy loam............	4.9	14.3	4.5	0.69	432	2.8	1.6	790	6.8
W. C. Thompson, Lynchburg sandy loam............	4.9	10.5	3.6	0.57	291	1.4	1.2	850	6.0
L. R. Mayo, Lynchburg sandy loam..	5.3	13.6	4.5	0.63	207	—	—	390	6.9

*First six locations are those of the phosphate experiments and the analyses are from 1945 samples. Potash experiments were located adjacent to each phosphate experiment except at the second location, plus one new location. The potash analyses are from 1946 samples.

The moisture conditions during the growing season were more favorable in 1946 than 1945. Over twice as much rain fell in the three months period, March, April, and May in 1946.

Maine.—Rate of phosphorus tests were conducted at nine locations in 1946 on soils which had a readily soluble phosphorus content ranging from 76 to 563 pounds P_2O_5 per acre. The rates of phosphorus applied were 0, 40, 80, 120, 160, and 200 pounds of P_2O_5 per acre. A 6×6 Latin square design was employed. The size of the plot harvested was 1/75 acre and consisted of four rows 50 feet long. Fifty-four feet of row was fertilized and planted, but 2 feet at each end of the plots were discarded. Treble superphosphate was used as the source of P_2O_5. The amount of calcium applied with each treatment was maintained constant by adding enough gypsum in each mixture equal to the difference in the calcium of the mixture and

[4]Exchangeable phosphorus and anion exchange capacity by L. A. Dean, Division of Soils, Fertilizers, and Irrigations, Plant Industry Station, Beltsville, Maryland. The remainder of the chemical analyses were conducted under the supervision of J. R. Piland and L. F. Seatz, N. C. Agr. Exp. Station, Raleigh, N. C.

that contained in the high phosphate mixture. All plots received a uniform application of nitrogen and potash (100 pounds of N and 200 pounds K_2O per acre). The sources of nitrogen were as follows: 65% from ammonium sulfate, 20% from nitrate of soda, 10% from calcium cyanamid, and 5% from tankage. Potash was supplied as muriate (60% K_2O). Equal amounts of magnesium were supplied from Michox (92% M_gO) and from limestone containing 10% M_gO, to supply a total of 30 pounds of M_gO per acre. The fertilizer was applied with a potato planter in bands, 2 inches to each side of and on a level with the lower plane of the seed piece. The Katahdin variety of potato was planted in all cases. The seed pieces were spaced 9 inches apart in rows 34 to 36 inches apart.

Samples of rachises (the extension or prolongation of the petioles) obtained consisted of the fifth rachis from bottom. (Ten rachises were obtained from a given treatment on each of three plots and combined to make one sample.) The first sampling was made in the early bud stage. Subsequent samplings were made at 10-day intervals. Three periodic samplings were made on four phosphorus rate tests. The fresh tissue was extracted with Morgan's Universal Extracting solution and soluble phosphorus was determined in the extract according to methods described by Wolf (13).

Specific gravity was determined by weighing tubers of approximately the same size in air and in water. Duplicate weighings of tubers were made on a sample from each of three replicates.

July moisture conditions in Maine were nearly satisfactory for potatoes in all areas where the experiments were located. During the first two and half weeks of August there was a lack of ample moisture in some areas of Aroostook, particularly in the central part at locations 1, 4, 7, and 9. Potatoes on all plots grew well after ample moisture was present during the remainder of August.

POTASH RATE EXPERIMENTS

North Carolina.—Rate of potash experiments were conducted at six locations in 1946, five of which were in the same field as rate of phosphorus experiments. These experiments were located on soils ranging from 169 to 451 pounds of exchangeable K_2O per acre. In five of the experiments conducted in Beaufort County four rates of potash were applied, namely, 0, 60, 120, and 180 pounds of K_2O per acre. These treatments plus one additional treatment not considered in this paper were arranged in a 5×5 Latin square. At the Tidewater Station an additional rate of 240 pounds per acre was added and four replications in a randomized block used. The dimensions of the plots and the method of applying the fertilizer were the same as used in the rate of phosphorus tests. The potash was supplied as the muriate. A uniform application of 120 pounds of N and 200 pounds of P_2O_5 per acre was made to all plots.

Leaves were sampled for potash analyses as described for the phosphorus experiments. Samplings were made on April 24 and May 13. Analyses were for total potash in the ashed plant material.

Tuber samples were obtained as already described for the phosphorus rate tests. The soil analyses are given in Table 1.

Maine.—Rate of potash experiments were conducted at eight locations, adjacent to eight of the phosphorus rate tests. The exchangeable potassium content of the soils ranged from 160 to 907 pounds of exchangeable K_2O per acre. Potash was applied at the rate of 0, 60, 120, 180, 240, and 300 pounds K_2O per acre. A 6×6 Latin square design was employed. The dimensions of the plots and the method of applying the fertilizer were the same as those used in the rate of phosphorus tests. All plots received the same amount of nitrogen and phosphorus (100 pounds of N and 160 pounds of P_2O_5 per acre). The fertilizer mixtures were made with materials as previously described.

Rachises were sampled for potassium analyses as in the rate of phosphorus experiments. A total of five samplings was made at periodic intervals of about 10 days, beginning with first sampling at early bud stage. Samples were obtained from three potash rate tests on soils low, medium, and high in exchangeable potassium.

The potassium in the fresh rachises was extracted with Morgan's Universal Extracting solution and determined turbidimetrically using a photoelectric colorimeter by the method described by Wolf (13).

RESULTS

PHOSPHORUS RATE EXPERIMENTS

North Carolina.—The 1945 and 1946 data by years are given in Table 2. There was a measurable response to applied phosphorus at all locations.

TABLE 2.—*Effect of applied phosphorus on total yield of Irish potatoes in cwts. per acre as related to the readily soluble phosphorus content of the soil, North Carolina, 1945–46 average.*

Lbs. of P_2O_5 per acre applied	Readily soluble phosphorus, pounds P_2O_5 per acre*					
	48	310	410	710	790	850
	Tide-water Sta., Bladen silt loam	R. S. Thomp-son, Ports-mouth sandy loam	H. M. Lewis, Ports-mouth fine sandy loam	I. W. Hola-dia, Ports-mouth loam	M. F. Thomp-son, Lynch-burg sandy loam	W. C. Thomp-son, Lynch-burg sandy loam
0 (6–0–8)........	82.4	147.5	165.6	171.6	142.3	162.4
40 (6–2–8)........	142.8	169.0	174.9	173.0	150.1	167.2
80 (6–4–8)........	167.9	184.3	187.3	185.7	160.0	172.2
120 (6–6–8)........	171.5	189.0	191.5	184.0	156.4	171.2
160 (6–8–8)........	181.5	192.4	198.8	186.0	164.2	181.0
L. S. D. (.05).........	16.7	13.3	14.6	10.0	11.3	8.0
(.01).........	22.7	18.7	20.4	—	15.8	11.2
C. V.%............	11	11	5	4	7	8
Increase from first 80 lbs. P_2O_5..........	85.4	36.8	21.7	14.1	17.7	9.8
Increase from second 80 lbs. P_2O_5........	13.7	8.1	11.5	0.3	4.2	8.8

*Readily soluble phosphorus by modified Truog method, soil sampled 1945.

On the low phosphate soils the response to the first 80-pound increment of P_2O_5 was quite large. As the soil phosphorus increased the response to the first increment of applied phosphorus decreased. In both 1945 and 1946 the analyses of leaves from plants which received no P_2O_5 show that the phosphorus content of the leaves is related to the readily soluble phosphorus content of the soil (Fig. 1).

A marked growth response to applied phosphorus was obtained on the soil containing 48 pounds of readily soluble P_2O_5 per acre. On the other soils there was an early growth stimulation from applications of P_2O_5, but no differences in growth were apparent later in the growing period.

The number of tubers per hill, individual tuber weights, and specific gravity of tubers of samples from treatments of 0 and 160 pounds of P_2O_5 per acre are given in Table 3. The number of tubers per hill was increased by the applied P_2O_5 at four of the locations. At the other two the number of tubers was relatively high and the size of the tubers was increased 22 and 23%, respectively.

Maine.—The yield data from the phosphorus rate tests conducted in 1946 are summarized in Table 4. Numerical but not statistically significant increases in yield of potatoes were obtained with each increment of phosphorus up to 200 pounds of P_2O_5 per acre in six of nine phosphorus rate tests. The soils at these locations contained 247 pounds P_2O_5 per acre or less of Truog soluble phosphorus. In two experiments where the readily soluble phosphorus content of the soil was 538 and 563 pounds of P_2O_5 per acre, no increase in yield of

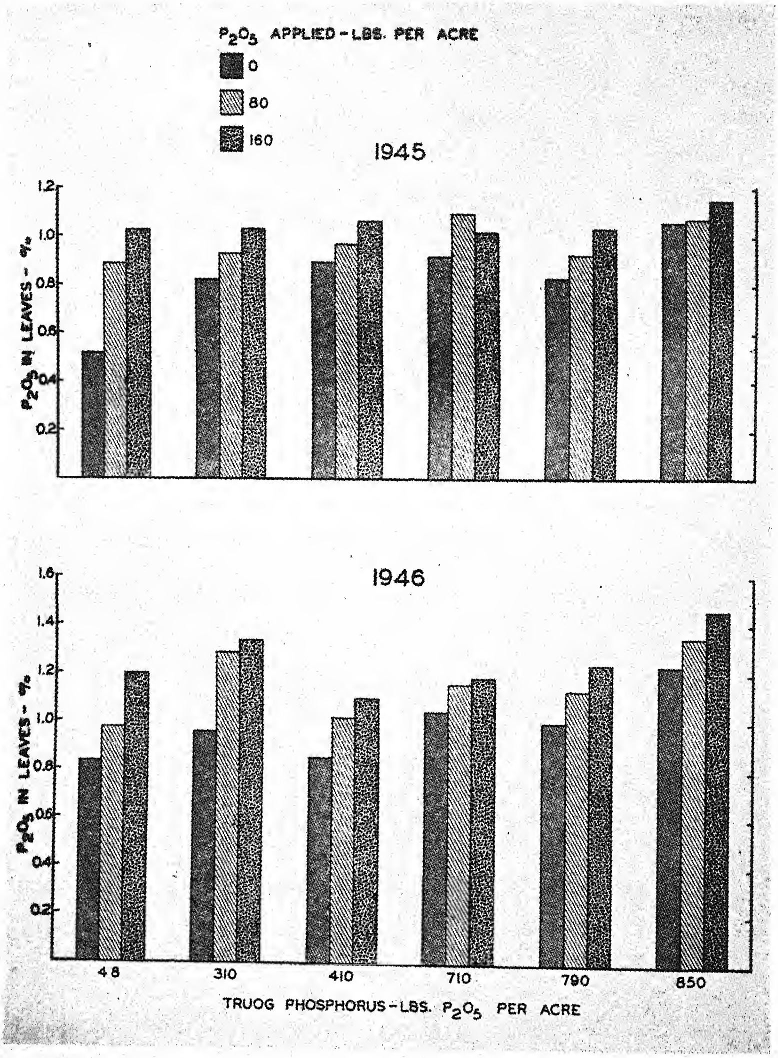

FIG. 1.—Total P_2O_5 content of potato leaves as related to treatment and to the amount in the soil, North Carolina, 1945–46.

TABLE 3.—*Effect of applied phosphorus on number of tubers per hill, individual weight and specific gravity, North Carolina, 1946.*

Lbs. per acre P_2O_5 in soil	Number per hill		Individual tuber weight, lbs.		Specific gravity	
	0, P_2O_5	160 lbs. P_2O_5	0, P_2O_5	160 lbs. P_2O_5	0, P_2O_5	160 lbs. P_2O_5
48	3.91	8.48	0.197	0.208	1.080	1.086
310	6.32	7.28	0.188	0.187	1.074	1.075
410	6.61	6.84	0.208	0.249	—	—
710	7.71	7.10	0.180	0.210	1.082	1.080
790	4.72	5.27	0.234	0.240	1.083	1.081
850	8.58	7.51	0.194	0.192	—	—

potatoes was obtained from applications of phosphorus greater than 80 to 120 pounds P_2O_5 per acre. The soluble phosphorus in the rachises at early bud stage is related to the amounts of P_2O_5 applied (Table 5).

The addition of 80 and 160 pounds of phosphorus per acre resulted in a slightly lower specific gravity of the tubers as compared with those produced with the no-phosphorus treatment (Table 9).

TABLE 4.—*Effect of applied phosphorus on total yield of Irish potatoes in cwts. per acre as related to the readily soluble phosphorus content of the soil. Maine, 1946.*

Lbs. of P_2O_5 per acre applied	Readily soluble phosphorus, pounds P_2O_5 per acre*								
	76	131	181	188	192	231	247	538	563
	Winslow, Isolation loam	Sides, Thorndike loam	Bouchard, Macomber loam	Belyea, Washburn loam	Morgan, Thorndike loam	Martin, Macomber loam	Ginn, Caribou loam	Perrin, Thorndike loam	Cook, Caribou loam
0 (5–0–10).....	127.9	251.8	172.4	194.0	239.1	235.9	136.1	255.2	305.7
40 (5–2–10).....	189.7	290.8	233.5	247.6	264.6	299.9	201.7	263.0	318.9
80 (5–4–10).....	234.7	300.1	269.6	276.1	280.4	323.2	206.9	267.2	330.2
120 (5–6–10).....	248.9	311.9	286.1	284.6	289.4	320.8	208.0	265.6	344.9
160 (5–8–10).....	247.1	313.7	294.1	288.8	285.8	343.1	217.9	248.5	332.6
200 (5–10–10)....	269.4	305.8	300.1	307.1	292.4	357.4	224.0	255.2	343.0
L.S.D. (.05)......	24.4	16.0	10.9	17.2	10.7	29.9	17.0	N.S.†	11.0
(.01)......	33.3	21.8	14.9	23.5	14.7	40.8	23.2	—	15.0
C. V., %.........	9.2	4.5	3.5	5.4	3.2	7.9	7.1	4.2	2.8
Increase from first 80 lbs. P_2O_5.....	106.8	48.3	97.2	82.1	41.3	87.3	70.8	12.0	24.5
Increase from second 80 lbs. P_2O_5	12.4	13.6	24.5	12.7	5.4	19.9	11.0	−18.7	2.4

*Readily soluble phosphorus by modified Truog method.
†Difference between treatments not statistically significant.

TABLE 5.—*Effect of applied phosphorus and level of readily soluble phosphorus in the soil on concentration of phosphorus in fifth rachises of potato plants (% of P on dry weight basis), Maine, 1946.*

Lbs. P_2O_5 applied per acre	Readily soluble phosphorus in pounds P_2O_5 per acre			
	76 Winslow	188 Belyea*	247 Ginn	563 Cook
0 (5–0–10)	0.030	0.036	0.079	0.033
40 (5–2–10)	0.033	0.078	0.132	0.095
80 (5–4–10)	0.045	0.139	0.125	0.079
120 (5–6–10)	0.072	0.115	0.145	0.103
160 (5–8–10)	0.099	0.227	0.173	0.131
200 (5–10–10)	0.104	0.289	0.186	0.179

*Belyea location soil had higher pH and available Ca than others.

POTASH RATE EXPERIMENTS

North Carolina.—There is a measurable yield response at all locations (Table 6). The response to the first 60-pound increment of K_2O is related to the amount of exchangeable potash in the soil. In five of the six experiments 180 pounds of K_2O gave an apparent response over the 120-pound application. The difference is significant on the two soils containing the highest amounts of exchangeable potash.

The analyses of leaves from plants which received the no-potash treatment show the potash content of the leaves to be related to the

TABLE 6.—*Effect of applied potash on total yield of Irish potatoes in cwts. per acre as related to the exchangeable potassium content of the soil, North Carolina, 1946.*

Lbs. of K_2O per acre applied	Exchangeable potassium, pounds K_2O per acre					
	169	207	291	301	432	451
	Tide. Sta., Bladen silt loam	L. R. Mayo, Portsmouth sandy loam	W. C. Thompson, Lynchburg, sandy loam	H. M. Lewis, Portsmouth, fine sandy loam	M. F. Thompson, Lynchburg sandy loam	I. W. Holadia, Portsmouth loam
0 (6–10–0)	186.8	163.6	154.3	176.9	128.5	170.0
60 (6–10–3)	237.1	183.7	186.1	196.9	143.3	177.2
120 (6–10–6)	258.9	188.0	184.0	209.1	144.8	188.7
180 (6–10–9)	271.4	195.5	182.1	217.8	153.2	197.1
L.S.D. (.05)	15.5	11.9	N.S.	12.4	7.8	6.9
(.01)	21.4	16.7	—	17.4	10.9	9.6
C. V., %	5	5	9	5	4	3
Increase from first 60 lbs. K_2O	30.3	20.1	31.8	20.0	14.8	7.2
Average increase from 2nd and 3rd 60-lb. increments of K_2O	17.2	5.9	−2.0	10.5	5.0	10.0

exchangeable potassium in the soil (Fig. 2). It is interesting to note that at the first sampling, the potash contents of the leaves from the 180-pound treatment were all in the range of 5.0 to 5.6%. On May 13, however, the potash contents of the leaves receiving this treatment were, with one exception, related to the exchangeable potassium in the soil. At this time tuber formation was rapid and there was considerable stress on the potassium supply in the plant.

The effects of an application of 120 pounds of K_2O per acre as compared with O K_2O at all locations on number of tubers per hill, indi-

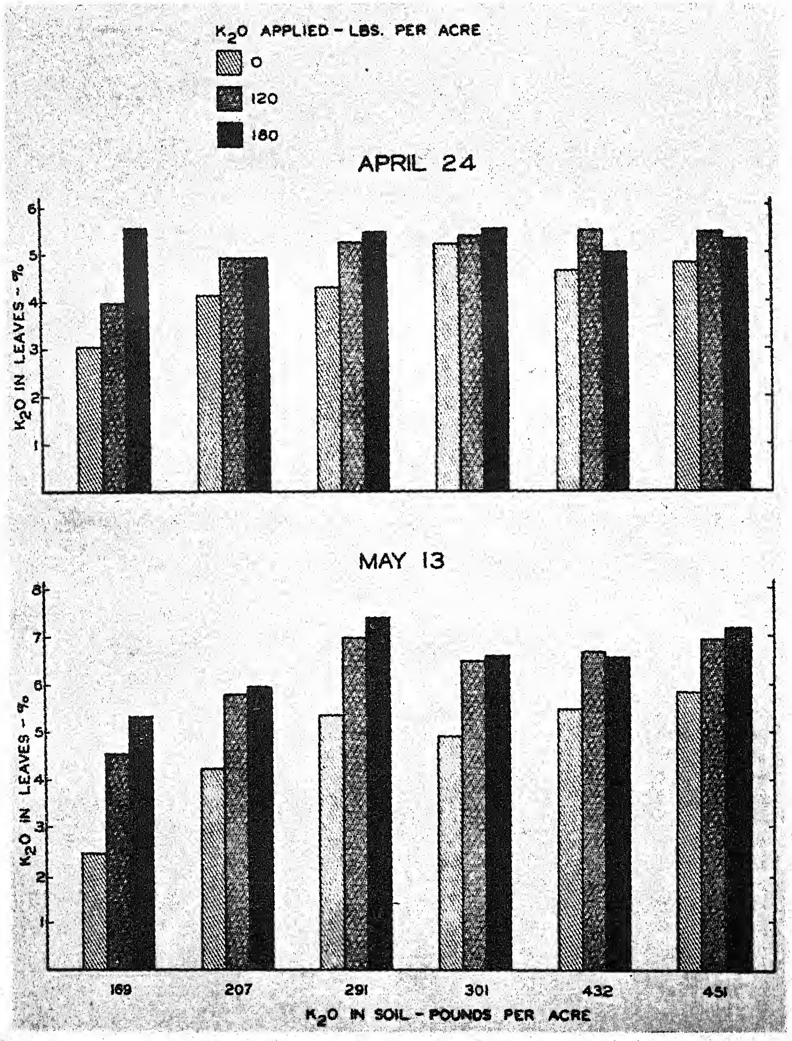

FIG. 2.—Total potash content of potato leaves as related to treatment and to exchangeable potassium content of the soil, North Carolina.

vidual tuber weights, and specific gravity are given in Table 7. The specific gravity data show that the addition of potash as muriate of potash resulted in a decrease in the specific gravity of the tubers at all locations except on the soil lowest in exchangeable potassium. Specific gravity is used as a measure of starch content. A reduction in the specific gravity of 0.005 is equivalent to reducing the starch content about 1%. The usual starch content of potatoes is in the range of 14 to 18%.

TABLE 7.—*Effect of applied potash on number of tubers per hill, individual tuber weight and specific gravity, North Carolina, 1946.*

K_2O in soil, lbs. per acre	No. per hill		Individual tuber weight, lbs.		Specific gravity	
	0, K_2O	120 lbs. K_2O	0, K_2O	120 lbs. K_2O	0, K_2O	120 lbs. K_2O
169	7.43	8.62	0.171	0.201	1.091	1.091
207	6.15	6.01	0.177	0.209	1.089	1.084
291	7.86	8.65	0.189	0.203	1.093	1.087
301	8.05	7.97	0.185	0.208	1.086	1.081
432	5.09	5.58	0.213	0.216	1.089	1.083
451	7.86	8.02	0.180	0.194	1.086	1.080

Maine.—The yield data from the potash experiments conducted in Maine are summarized in Table 8. Increases in yield were obtained from treatment at all locations with the differences being significant on only five of the eight experiments.

TABLE 8.—*Effect of applied potash on total yield of Irish potatoes in cwts. per acre as related to the exchangeable potassium content of the soil, Maine, 1946.*

Lbs. of K_2O per acre applied	Exchangeable potassium, pounds K_2O per acre							
	160	165	287	414	470	484	747	907
	Bel-yea	Mor-gan	Mar-tin	Sides	Bou-chard	Ginn	Cook	Perrin
0 (5–8–0)	231.5	235.6	335.9	316.4	275.7	212.5	307.0	228.7
60 (5–8–3)	266.3	272.5	354.4	335.0	288.5	226.6	325.2	240.2
120 (5–8–6)	268.6	277.3	351.1	344.0	297.3	230.6	328.6	260.7
180 (5–8–9)	274.7	285.1	367.6	343.5	284.7	228.2	330.7	267.9
240 (5–8–12)	280.4	282.3	368.5	332.8	289.4	224.8	328.3	264.2
300 (5–8–15)	267.8	276.5	358.5	336.6	283.1	227.3	329.8	280.1
L.S.D. (.05)	N.S.	19.4	N.S.	14.2	12.3	N.S.	14.3	29.2
(.01)	—	26.5	—	19.3	—	—	19.5	—
C. V., %	10.5	5.9	6.5	3.5	5.6	5.6	3.6	9.4
Increase from first 60 lbs. K_2O	34.8	36.9	18.5	18.6	12.8	14.1	18.2	11.5
Average increase from 2nd and 3rd 60 lbs. increments of K_2O	4.2	6.3	6.6	4.3	−1.9	0.8	2.8	13.9

There is a general relationship between the degree of response to the first 60 pounds of K_2O and the amount of exchangeable potassium in the soil. Apparent increases in yield were obtained with increased rates of application of potash up to 240 pounds of applied K_2O per acre on a soil which contained 160 pounds of exchangeable potash per acre. Maximum yields were obtained with 180 pounds of applied K_2O at two other locations where the soil contained less than 300 pounds of exchangeable potash.

The amount of potassium extracted from rachises of the potato plant is related to the exchangeable potassium content of the soil (Fig. 3). The difference in the potassium content of the rachises from plants growing on soils containing low, medium, and high amounts of exchangeable potassium was greater at the later dates of sampling.

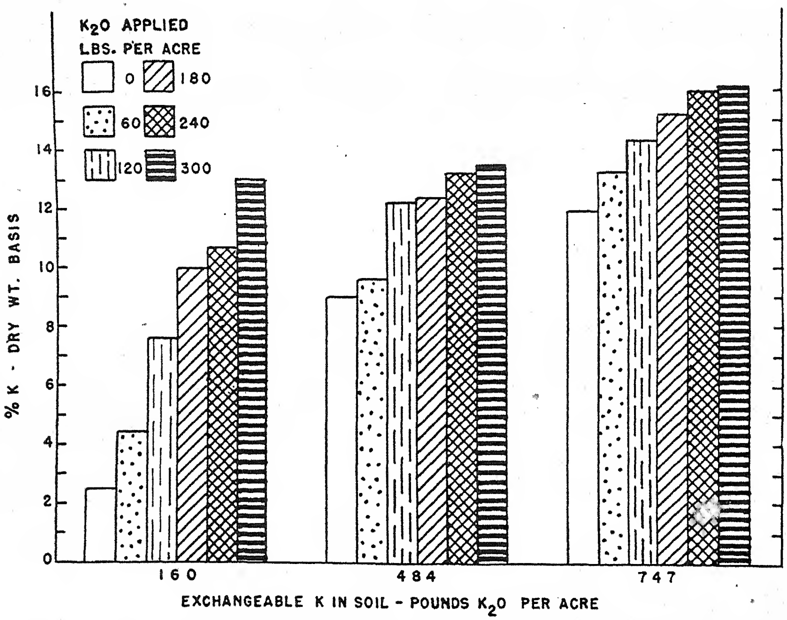

FIG. 3.—Potassium extracted from fresh rachises as related to amount of potash applied and exchangeable potassium content in the soil. Sampled about 35 days after early bud stage, Maine.

The specific gravity of the tubers produced decreased with increased application of potash as muriate of potash (Table 9). The decreases were about the same regardless of the exchangeable potash in the soil.

DISCUSSION

The amount of potatoes produced by the first 80-pound increment of P_2O_5 applied decreases as the amount of phosphorus in the soil increases (Fig. 4). Irish potatoes is a crop with a limited root system and it may be necessary to supply the nutrients in a relatively limited zone. Brown (2) found considerable benefit from localized placement

TABLE 9.—*Specific gravity of Katahdin grown with different rates of phosphorus and potash on soils having different levels of these nutrients, Maine, 1946.*

Lbs. P_2O_5 per acre applied	Readily soluble phosphorus in pounds P_2O_5 per acre			
	76 Winslow	188 Belyea	247 Ginn*	563 Cook
0 (5-0-10)	1.074	1.077	1.074	1.073
80 (5-4-10)	1.072	1.075	1.073	1.074
160 (5-8-10)	1.073	1.073	1.070	1.072
Lbs. K_2O per acre applied	**Exchangeable potassium, pounds K_2O per acre**			
	160 Belyea	470 Bouchard	484 Ginn*	747 Cook
0 (5-8-0)	1.083	1.082	1.078	1.082
120 (5-8-6)	1.078	1.074	1.073	1.076
240 (5-8-12)	1.072	1.073	1.069	1.071
300 (5-8-15)	1.073	1.070	1.068	1.073

*Only one replicate sampled.

of phosphorus. This would encourage more rapid development and earlier maturity. Diseases often interfere with the normal maturity of Irish potatoes and over a period of years earlier maturity should favor increased yields.

The nature of the yield curve suggests that when 40 to 80 pounds of

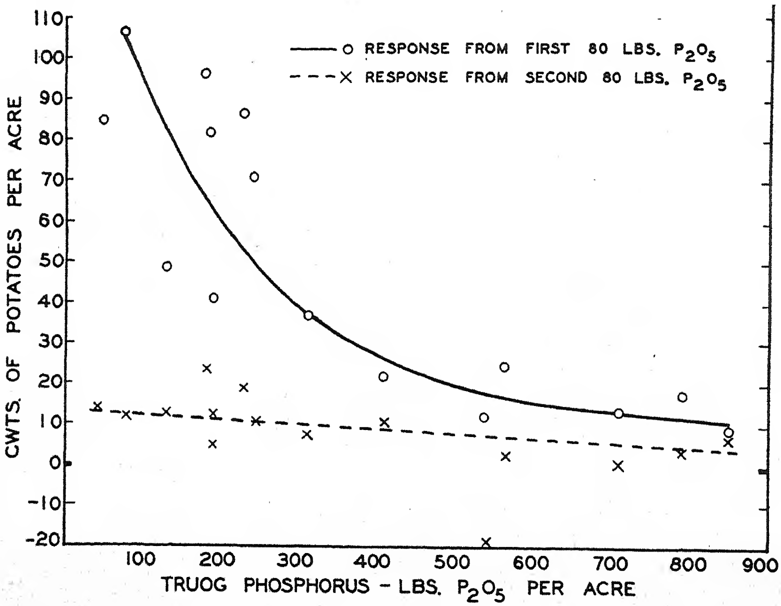

FIG. 4.—Returns from first and second 80-pound increments of P_2O_5 as related to the amount of phosphorus in the soil, Maine and North Carolina.

P_2O_5 produce reasonably large increases the response is a direct nutrient effect. Otherwise, the small increases suggest an indirect effect of phosphorus on plant growth. The effect of phosphorus in inactivating soluble aluminum or other elements might be a possibility.

The amount of potatoes produced by the first 60-pound increment of K_2O decreases as the amount of exchangeable potash in the soil increases (Fig. 5). The response to potash might be explained when one considers that the requirement of the potato plant for potassium is very large and that the root system is not extensive. The potash absorption rate is also very high for a short period of time. Data obtained in Maine revealed that during the peak period of potash absorption (70 days after planting with the Green Mountain variety) upwards of 6.4 pounds of K_2O per acre per day were absorbed (8).

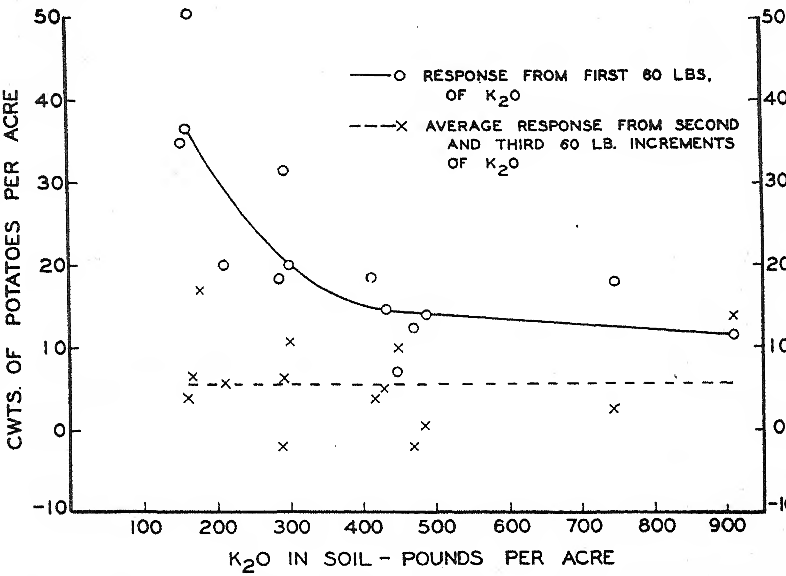

FIG. 5.—Returns from applied K_2O as related to the amount of exchangeable potassium in the soil, Maine and North Carolina.

SUMMARY

Field experiments were conducted in Maine and in North Carolina to determine the effects of rates of phosphorus and potash applied to Irish potatoes grown on soils having a wide range in readily soluble phosphorus and exchangeable potassium.

An average of the 1945 and 1946 yield data from North Carolina shows that applied phosphorus gave significant increases in yield at all six locations. Significant increases in yield were obtained on eight of the nine experiments in Maine.

The degree of yield response to applications of P_2O_5 is related to the amount of readily soluble phosphorus in the soil. The increase in

number of pounds of potatoes resulting from the first 80 pounds of P_2O_5 applied decreases as the amount of readily soluble phosphorus in the soil increases.

Data from North Carolina reveal that the phosphorus content of the leaves is related to the amount of readily soluble phosphorus in the soil and to the amount of phosphorus applied. In the experiments in Maine the phosphorus content of the rachises sampled during the early bud stage was related to the amount of phosphorus applied.

It was revealed that phosphorus was particularly important in influencing the number of tubers per hill on soils low in readily soluble phosphorus.

Significant increases in yield from applied potash were obtained in all experiments in North Carolina and in five out of eight experiments in Maine.

The number of pounds of potatoes resulting from the first 60 pounds of K_2O applied tends to decrease as the amount of exchangeable potash in the soil increases.

Data from North Carolina reveal that the potash content of the leaves is related to the amount of potash in the soil and to applied potash up to 120 pounds of K_2O per acre. Similarly, in the Maine experiments, the amount of potassium extracted from rachises of the potato plant is related to the exchangeable potash content of the soil and to the amount of potash applied.

The results of the potash tests in Maine indicate that considerably more potash is applied by most growers than is necessary for maximum yields. On the other hand, the results obtained in North Carolina indicate that increased yields may be obtained with applications of potash greater than the 120 pounds of K_2O per acre normally applied to potatoes in that state.

LITERATURE CITED

1. BROWN, B. A. Fertilizers for potatoes in southern New England. Amer. Fert., 90 (4):9. 1939.
2. BROWN, B. E. Further studies on the placement of fertilizer for potatoes. Amer. Pot. Jour., 16:81–93. 1939.
3. BUSHNELL, JOHN. The possibility of reducing the proportion of P_2O_5 in fertilizer applied to sandy soils. Amer. Pot. Jour., 20:153–156. 1943.
4. CAROLUS, R. L. Influence of nitrogen, phosphorus, potassium and calcium on tuber and foliage weight of potatoes. Amer. Pot. Jour., 21:197–202. 1944.
5. CHUCKA, J. A., HAWKINS, ARTHUR, and BROWN, B. E. Potato fertilizer-rotation studies on Aroostook Farm 1927–1942. Me. Agr. Exp. Sta. Bul. 414. 1943.
6. CUMMINGS, R. W., PEECH, MICHAEL, and HAWKINS, ARTHUR. Nutrient status of soils in commerical potato producing areas of the Atlantic and Gulf coast: Parts 1, 2, and 3. Soil Sci. Soc. Amer. Proc., 10:240–256. 1946.
7. HAWKINS, ARTHUR. Absorption of major nutrient elements by different varieties of potatoes in Aroostook County, Maine. Doctorate dissertation submitted to Rutgers University. May 1943.
8. ———. Rate of absorption and translocation of mineral nutrients by potatoes in Aroostook County, Maine, and their relation to fertilizer practices. Jour. Amer. Soc. Agron., 38:667–681. 1946.
9. SCHRUMPF, W. E. Costs and practices in producing potatoes in Central Aroostook County, Maine, 1940. Me. Agr. Exp. Sta. Bul. 424. 1943.
10. ———. Costs and practices in producing potatoes in Southern Aroostook County, Maine, 1941. Me. Agr. Exp. Sta. Bul. 432. 1944.

11. WARE, L. M. Residual effect of phosphorus on Irish potatoes in south Alabama. Proc. Amer. Soc. Hort. Sci., 41:265–269. 1942.
12. WILLIAMS, C. B., MANN, H. B., and SKINNER, J. J. Results of five years' fertilizer experiments with Irish potatoes in eastern North Carolina. N. C. Agr. Exp. Sta. Bul. 283. 1933.
13. WOLF, B. Rapid determinations of soluble nutrients in soil and plant extracts by means of a photoelectric colorimeter. Ind. and Eng. Chem., Anal. Ed., 15:248–251. 1943.

Compactibility of Certain Soils as Related to Organic Matter and Erosion[1]

GEORGE R. FREE, JOHN LAMB, JR., AND EVERETT A. CARLETON[2]

MUCH of the interest in compaction of soil has been confined to the engineering field. There, maximum compaction and stability for construction of roads, dams, or landing strips at airports has been the chief aim. Those concerned with the use of soils for crop production are interested in soil compaction also. For the most part, however, emphasis has been placed on the existing degree of compaction and on aggregation and porosity relationships rather than on the degree of compaction that can be secured under mechanically applied forces.

The association of organic matter with soil structure and state or degree of compaction is generally recognized. Bradfield (5)[3] in comparing the tilled soils with soils in the virgin condition called attention to this. Compaction resulting from tractors and disks in orchards of California has been discussed by Parker and Jenny (15). They show that organic matter in the surface soil protects the subsoil against compaction. Some observations by G. N. Hoffer[4] on the importance of tap-rooted legumes in penetrating compacted layers in the soil and adding organic matter to increase the resistance of the soil to compaction were recently published.

It has been shown by Lawton (12) that packing of soil caused a marked reduction in growth of corn by decreasing aeration. Smith and Cook (17), working with sugar beets, found that the effect of compaction in lowering growth and yields was more serious than the addition of excess water.

In a recent preliminary study of soil compaction and certain factors affecting it, data have been obtained which promise wide agricultural application. These data will be presented and discussed in this report.

PROCEDURE

Most of the compaction data reported were obtained by using the equipment and procedure described by Proctor (16), except that for this study the compacting ram was dropped from a height of 6 rather than 12 inches. The amount of work done in packing each sample (this height × the total number of blows × the weight of the ram) was at the rate of 51 foot-pounds per pound of dry soil. Preliminary studies were conducted to determine the degree of compaction that might be reached under moderately severe conditions in the field. A Honeoye silt loam having a moisture content of 23%, and a volume weight of 1.32 to a 2-inch depth was compacted to a volume weight of 1.50 by one trip over it with an empty farm truck or tractor. When the moisture content was 19%, the volume

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[2]Soil Conservationist, Project Supervisor, and Soil Scientist, respectively. The authors wish to acknowledge the assistance given by Professor M. B. Russell of Cornell University.

[3]Figures in parenthesis refer to "Literature Cited", p. 1076.

[4]Tap-rooted legumes are antidote for hard plow-soles. From Agronomic Notes, National Fertilizer Association, April 9, 1947.

weight was increased from 1.24 to 1.58 by four trips with an empty truck. The 6-inch drop gave volume weights of this magnitude, whereas the standard 12-inch drop gave volume weights ranging from 1.65 to 1.70 for this particular soil.

After the compaction standard for laboratory tests was thus established, a number of samples of each soil was compacted at difference moisture contents to give a compaction-moisture curve for that soil. Several of these large cores were first used to obtain percolation data for one phase of the study. Later, small cores were found more convenient and adequate. These were compacted in small cylinders (2-inch diameter and 2½ inches long) with a packing ram 1 inch in diameter, and weighing 0.83 pound. The soil was compacted in three layers using 12 strokes of the ram for each layer. Twelve samples each of two different soils were compacted in these cylinders at different moisture contents. Six of each set of 12 were compacted by dropping the ram from a height of 9 inches, and six by dropping the ram only 3 inches. The amount of work done in packing was at the rate of 51 foot-pounds per pound of dry soil for the 9-inch drop and 17 for the 3-inch drop. Theoretically, the compaction from the 9-inch drop should be approximately the same as that from the modified Proctor method used for the main part of the study. It will be seen later, however, that the compaction-moisture curves obtained were somewhat different. This was probably partly due to differences in the action of the compacting rams in large and in small cylinders and to increased error in measuring volumes of the small cylinders and cores.

A measure of the water permeability of the small compacted cores was obtained by timing the disappearance of a head of 0.4 inch of water. No attempt was made to arrive at steady values, and additional water was applied only in the case of some of the more permeable cores.

The soils used were all from New York State. All samples were screened through a square-mesh sieve with 1/4-inch openings and then air-dried. The soils included in this study were Honeoye silt loam from the Marcellus field station, about 15 miles west of Syracuse; Bath flaggy silt loam from the erosion plots at the Arnot station, southwest of Ithaca; Ontario sandy clay loam from the erosion plots at Geneva; and Sassafras silt loam from eastern Long Island. Descriptions and erosion data for the soils are shown in Table 1. The first three soils are further described elsewhere (9, 11).

RESULTS

Compaction-moisture curves for samples from two sets of erosion plots on Honeoye soil are shown in Fig. 1. The chief differences in the curves for the various soil samples are (a) the maximum density or volume weight, and (b) the moisture content at which this maximum occurred. For this reason, these values for all of the samples tested are given in Table 2, instead of presenting the complete curves. The modified Proctor method of packing and 4-inch diameter cylinders were used to obtain the compaction data given in Fig. 1 and Table 2. Also given in Table 2 are data on organic matter for all samples and data on moisture equivalents and lower plastic limits for some. Further comparisons of compaction characteristics of two samples of Honeoye are given in Fig. 2. These data were obtained by using the 2-inch diameter cylinders and small ram.

DISCUSSION

The compaction characteristics of the eight samples of Honeoye (Table 2) tend to fall into three groups, depending upon the amount of past erosion and the present level of organic matter. In the first group are the samples from the C and D plots, which have the highest organic matter. In the second or intermediate group are the samples from field areas N and S. The other four samples with organic matter less than 3% make up the third group. The crop on the land appears to

TABLE 1.—*Source and descriptions of samples used for compactibility tests.*

Soil type	Samples areas	Locations	Slope, %	Management	Crop when sampled	Degree of erosion
Honeoye	C plots, field 7	Marcellus station	5	Rotation—corn, oats, clover since 1939	Clover	Slight
Honeoye	D plots, field 13	Marcellus station	9	Rotation—corn, oats, clover since 1939	Clover	Slight
Honeoye	N plots, field 8	Marcellus station	10	Rotation since 1942	Corn	Moderate
Honeoye	S plots, field 10	Marcellus station	6	Rotation	Corn	Moderate
Honeoye	O plots, field 10	Marcellus station	17	Rotation	Corn	Considerable
Honeoye	R plots, field 10	Marcellus station	17	Rotation	Alfalfa, timothy sod	Considerable past erosion
Honeoye	B plots, field 7	Marcellus station	17	Rotation—corn, oats, clover since 1939	Clover	Considerable past erosion
Honeoye	J plots, field 7	Marcellus station	17	Rotation since 1943	Corn	Considerable past erosion
Sassafras	Fence row	Eastern Long Island farm	1–2	Virgin area	Virgin area	Slight
Sassafras	Cultivated field adjacent to fence row	Eastern Long Island farm	1–2	Intensive cultivation	Potatoes, cauliflower, etc.	Slight
Bath	Plot A-9	Arnot station	20	Sod since 1935	Sod	Slight
Bath	Plot A-8	Arnot station	20	Fallow since 1935	Fallow	Severe
Ontario	Plot 6	Geneva station	8	Sod since 1936	Sod	Slight
Ontario	Plot 5	Geneva station	8	Fallow since 1936	Fallow	Severe

TABLE 2.—*Summary of results of compactibility tests with data on organic matter, moisture equivalents, and lower plastic limits.*

Soil	Sample	Volume weight at maximum compaction	Moisture at maximum compaction, %	Organic matter, %	Moisture equivalent	Lower plastic limit*
Honeoye	C plots	1.47	26.0	4.1	25.2	26.7
Honeoye	D plots	1.49	25.0	4.1	25.1	—
Honeoye	N plots	1.54	22.5	3.3	—	—
Honeoye	S from field 10	1.54	24.0	3.0	—	—
Honeoye	O from field 10	1.59	21.5	2.8	—	—
Honeoye	R from field 10	1.61	21.0	2.8	—	—
Honeoye	B plots	1.60	20.5	2.8	21.6	21.8
Honeoye	J plots	1.61	22.0	2.5	22.0	—
Sassafras	Virgin	1.48	26.1	4.4	—	28.2
Sassafras	Cultivated	1.69	18.9	2.6	—	23.2
Bath	Plot A-9	1.49	26.0	4.5	—	27.5
Bath	Plot A-8	1.63	22.4	3.0	—	22.8
Ontario	Plot 6	1.71	17.5	2.4	16.1	19.2
Ontario	Plot 5	1.81	15.0	1.3	14.4	16.4

*Samples were rolled to rods about ¼ inch in diameter.

be a factor of considerably less importance than organic matter and past erosion.

Samples in the first group were compacted to a maximum volume weight of 1.5, whereas samples from the third group were compacted to a maximum volume weight of 1.6. The moisture content at which maximum compaction occurred was approximately 25% for the

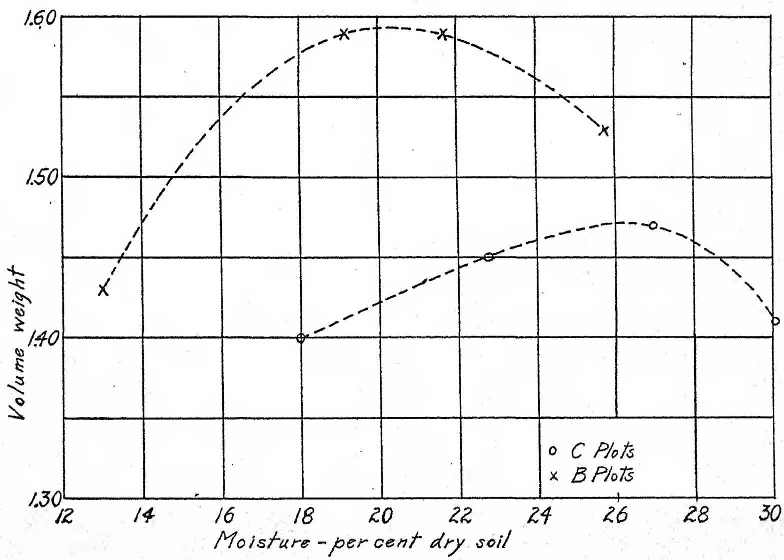

FIG. 1.—Compaction-moisture curves for soil samples from B and C plots on Honeoye silt loam. Large cylinders.

first group and approximately 21% for the last group. A sample in the low-organic-matter group yielded the volume weight of 1.5 at a

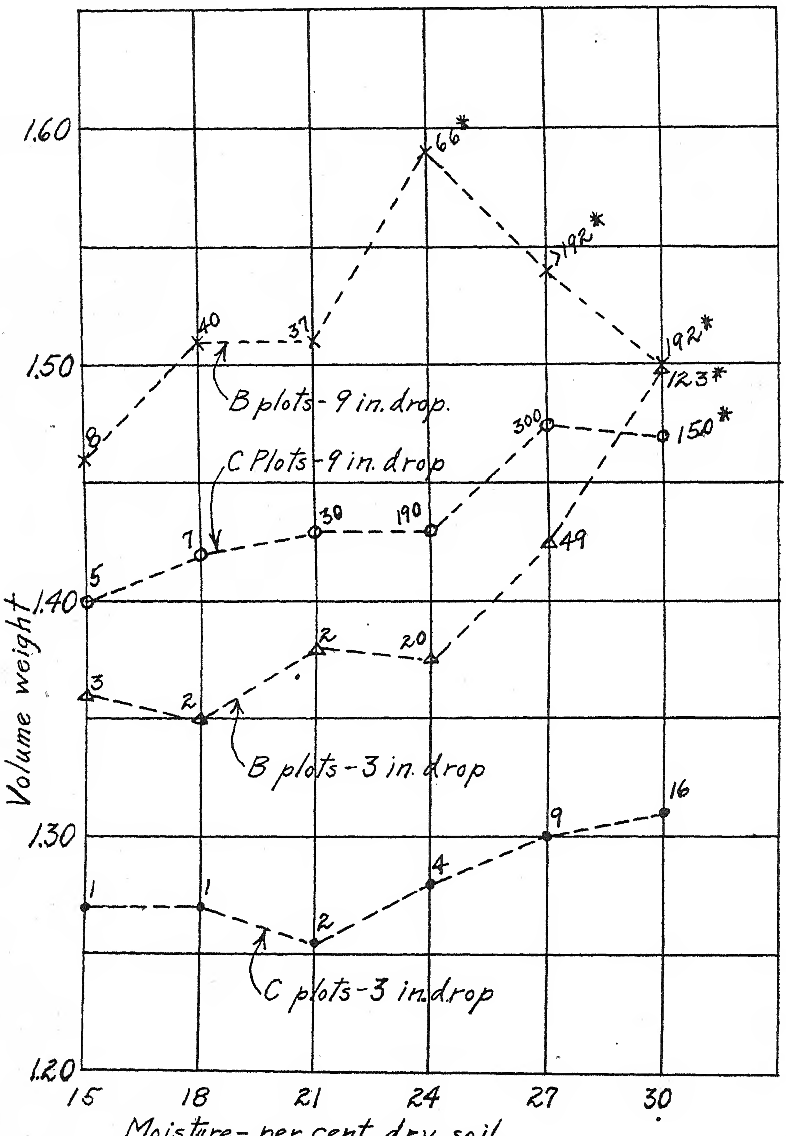

FIG. 2.—Compaction-moisture curves for soil samples from B and C plots on Honeoye silt loam. Small cylinders. Two different intensities of packing as shown. Figure by each plotted datum is the number of minutes required for disappearance of head of 0.4 inch of water except that those values marked with asterik are hours instead of minutes.

moisture content of 15%, as indicated in Fig. 1. The high organic-matter group could be worked with 10% more moisture before compacting to the same degree. Compaction-moisture curves from data for samples of Sassafras, Bath, and Ontario soils show the same tendency to vary with organic matter. Apparently, organic matter not only determines the moisture content at which maximum compaction occurs for a given soil, but also has a marked influence on the amount of compaction. It is recognized, of course, that maximum compaction, and also the moisture content at which it occurs will for a given sample, vary with the compacting force.

Baver (2) in 1930 concluded that the range of maximum compressibility was approximately the same as the plasticity range on the moisture scale, and that maximum compressibility was an inverse logarithmic function of the plasticity number. He did not describe his method of packing except to state that the force was of the magnitude generally used for tillage. In an earlier study he (1) reported that oxidation of the organic matter in the soil by hydrogen peroxide produced a marked lowering of both the upper and lower plastic limits with only a slight tendency to decrease the plasticity number. It would thus appear that organic matter should have little effect on maximum compactibility except to be a factor determining the moisture content at which it would occur. The soils he used were mostly of fairly heavy texture.

In order to relate compactibility to plasticity number, it would be necessary that the soil be plastic. Baver (3) states that soils containing less than 15% clay are generally nonplastic. Many of the samples used for the present study were undoubtedly border line with respect to plasticity. Some rough determinations of lower plastic limits were made and all values were greater than the moisture equivalents. Olmstead (14), in reporting moisture relations of soil samples from 11 profiles at the erosion experiment stations, stated that soils near the border line between plastic and nonplastic consistencies gave values for the lower plastic limit which approached or occasionally slightly exceeded the moisture equivalent. He was able to classify only 5 of the 11 surface soils as definitely plastic.

The lower plastic limits for the low-organic-matter samples of each soil in this study (table 2) were from 3 to 5% lower than those for the high-organic-matter samples.

Early in the study, permeability tests were made on 15 of the large cores of compacted Honeoye soil. The volume weights ranged from 1.45 to 1.62, and the moisture contents at which they were compacted ranged from 17 to 29%. Heads on the surface of the samples were held at ¼ inch so that the results would have practical significance in terms of infiltration and percolation under field conditions. The maximum percolation rate was 0.05 inch per hour for one sample compacted to a volume weight of 1.53 at a moisture content of 17%. Another sample of this same soil compacted to a volume weight of 1.58 at a moisture content of 20% had a percolation rate less than 0.01 inch per hour. No water at all moved through 10 of the samples in tests lasting from 3 to 7 days.

The data in Fig. 2 have several points of interest since a sample with

a high level of organic matter and a sample from the same field with a low level of organic matter because of past erosion are compared at two intensities of packing over a wide range of moisture. The effects of moisture, intensity of packing, and organic matter on compaction and permeability are all quite marked. Another effect to be noted is that whereas the compaction curve shows a decrease in volume weight beyond the moisture content at which the maximum occurs, permeability does not return to the same value as on the dry side of the curve. This may be due to a puddling action where the ram strikes the soil, or it may just be another indication that permeability is related to size and continuity of pores rather than volume. Proctor (16) called attention to the fact that the peaks of compaction-moisture curves for the same soil occurred at lower moisture contents as the peak dry or volume weight increased. Although peak volume weights may not have been reached in all of the compaction-moisture curves of Fig. 2, agreement with this general principle is apparent. Both organic matter and intensity of packing determine peak volume weight, and hence both also determine the moisture content at which it occurs.

Probably the most important finding in this study is that the compactibility and permeability of soils under mechanically applied forces is associated with organic matter. Organic matter on sloping soil is associated with erosion. It must also be recognized, however, that physical characteristics of certain soils may or may not be affected by *additions* of fresh organic matter. The data reported by Bertramson and Rhoades (4) are a striking example of this.

PRACTICAL APPLICATIONS

It is evident that the dominant factors determining the compaction of soils are (a) the magnitude and nature of the compacting forces, (b) the moisture content of the soil, (c) the degree of compaction of the soil at the time the compacting forces act on it, and (d) those more stable characteristics of the soil, such as texture, organic matter, etc.

The caution that we should not work or "get onto" a soil when it is wet is a familiar one. The "wetness" of a soil is, of course, a relative term. The farmer of yesterday with less power at his command was less likely to work or get onto a soil when it was too wet than the farmer of today. The increase in power has been accompanied by an increase in compacting forces. These are the vibration, magnitude, number, and distribution of impacts. Compaction in this study was compared with that resulting from a tractor or an empty farm truck. Certainly greater compaction would be associated with the loaded truck or other equipment, such as spray rigs carrying large volumes of water. Farmers will work and "get onto" soils when they are too wet to plow. Probably one reason for this, aside from the practical consideration of getting the job done, is that compaction is less obvious than "shiny" furrows.

Would elimination of the traffic of heavy equipment over wet or moist cropland do away with our interest in compactibility? Prob-

ably not, since there would still be the important problems of compaction resulting from trampling of livestock and soil packing or mechanical compaction by rain drops. The latter plays an important role in the formation of the thin surface crust which Duley (7) has shown to have such a marked effect on infiltration. In discussing the formation of this sealing layer, he speaks of its having a high volume weight but believes it is due to the action of the raindrops fitting some of the finer particles around the larger ones rather than to an increase of fine material. He shows that this smooth layer was formed even on sand when it was sprinkled. Horton (10) also has discussed rain-packing as related to infiltration capacity.

Association of crust formation with the degree of past erosion and present level of organic matter on the Dunkirk soil at Geneva has been discussed elsewhere (9). Carleton (6), in a later report, presents data showing the number of blows required to penetrate the soil crust after a packing rain. When the soil was still moist (24%), the number of blows was three for an area where the organic matter was 1% and the same where the organic matter was 3%. However, when soil moisture in the surface layer fell to 4% (about 3½ days after the rain), the number of blows was 40 and 12, respectively, for the two areas.

Erodibility of Honeoye soil at Marcellus has been shown to be markedly affected by the degree of past erosion and present level of organic matter (8). Most of the data in that paper were from the C, D, and B plots (Table 1). The erosion losses from these plots in the order named were in the ratios of 1:2:35, while the surface runoff losses were in the ratios of 1:1:3. The values of volume weights at maximum compaction in this study were 1.47, 1.49. and 1.60.

The compacting forces used in this study may be compared with those associated with rainfall. It has been stated (13) that a 2-inch rain may exert 6 million foot-pounds of kinetic energy per acre. If we assume that this acts on the surface ½ inch, a rain of 2½ inches would expend energy amounting to 50 foot-pounds per pound of dry soil. Actually the thickness of the sealing crust is probably not as much as ½ inch, and it is known that the kinetic energy of falling rain varies over a wide range with varying size of drop.

SUMMARY

Data on compactibility of certain soils in New York State have been presented and discussed. Within each of the four soil series represented in the study, comparisons were made of compaction-moisture curves for samples differing in the amount of organic matter they contained. The samples containing the most organic matter were compacted to a lesser degree by a given compactive effort at a given soil moisture content. Furthermore, the moisture content at which maximum compaction occurred was higher. For three of the four series studied, the differences in organic matter were directly related to the extent of past erosion—either measured or observed.

The data were discussed from the standpoint of practical application, and also from the standpoint of possible significance in the formation of surface crusts on the soil.

LITERATURE CITED

1. BAVER, L. D. The effect of organic matter upon several physical properties of soils. Amer. Soc. Agron. Jour., 22:703–708. 1930.
2. ————. The Atterberg consistency constants: Factors affecting their values and a new concept of their significance. Amer. Soc. Agron. Jour., 22:935–948. 1930
3. ————. Soil Physics. New York: John Wiley & Sons, Inc. 1940.
4. BERTRAMSON, B. R., and RHOADES, H. F. The effects of cropping and manure applications on some physical properties of a heavy soil in Eastern Nebraska. Soil Sci. Soc. Amer. Proc., 3:32–36. 1939.
5. BRADFIELD, RICHARD. Soil conservation from the view point of soil physics. Amer. Soc. Agron. Jour., 29:85–92. 1937.
6. CARLETON, E. A. (Geneva section) Annual progress report 1946 cooperative research between Soil Conservation Service, U.S.D.A., and New York State Agricultural Experiment Stations, Geneva and Cornell, 19–26. Mimeo 1947.
7. DULEY, F. L. Surface factors affecting the rate of intake of water by soils. Soil Sci. Soc. Amer. Proc., 4:60–64. 1940.
8. FREE, GEORGE R. Evidences of the effect of erosion on the organic matter and erodibility of Honeoye soil. Amer. Soc. Agron. Jour., 38: 207–217. 1946.
9. ————, CARLETON, E. A., LAMB, JOHN, JR., and GUSTAFSON, A. F. Experiments in the control of soil erosion in Central New York. Cornell Univ. Agr. Exp. Sta. Bul. 831. 1946.
10. HORTON, ROBERT E. An approach toward a physical interpretation of infiltration capacity. Soil Sci. Soc. Amer. Proc., 5:399–417. 1941.
11. LAMB, JOHN, JR., ANDREWS, J. S., and GUSTAFSON, A. F. Experiments in the control of soil erosion in southern New York. Cornell Univ. Agr. Exp. Sta. Bul. 811. 1944.
12. LAWTON, KIRK. The influence of soil aeration on the growth and absorption of nutrients by corn plants. Soil Sci. Soc. Amer. Proc., 10:263–268. 1946.
13. NICHOLS, M. L., and GRAY, R. B. Some important farm machinery and soil conservation relationships. Agr. Engin., 22:No. 10. 1941.
14. OLMSTEAD, L. B. Some moisture relations of the soils from the erosion experiment stations. U.S.D.A. Tech. Bul. 562. 1937.
15. PARKER, E. R., and JENNY, H. Water infiltration and related soil properties as affected by cultivation and organic fertilization. Soil Sci., 60:353–376. 1945.
16. PROCTOR, R. R. Fundamental principles of soil compaction. Engin. News-Rec., 111:Aug. 31, Sept. 7, 1933.
17. SMITH, FLOYD W., and COOK, R. L. Sugar beets require adequate soil aeration. Better Crops with Plant Food, 31:No. 3. 1947.

Reaction of Oat Varieties and Selections to Physiologic Races A–30 and A–31 of Loose Smut[1]

George M. Reed, T. R. Stanton, and George J. Wilds[2]

THE determination of the reaction of oat varieties and selections to the new physiologic races of the oat smuts that appear from time to time is necessary for conducting rational programs for breeding for resistance. In recent years, new races have appeared that are virulent on many of the new improved varieties, hitherto considered highly resistant. These new pathogens are making the problems of physiologic race specialization and breeding for resistance much more difficult. Results of the reaction of oat varieties to two of these new races are reported herein.

The introduction of the Victoria variety has been of importance in the improvement of oats, although the rather recent discovery of its high susceptibility to *Helminthosporium victoriae* and the close linkage in inheritance between susceptibility to this disease and the Victoria type of resistance to crown rust has made the variety less valuable for breeding. The seed was first obtained by the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, in 1927, a second shipment being received in 1929. The earliest history of the variety indicates that it was grown at La Estanzuela, Uruguay, in 1915 (6).[3] In the following years it was grown there and in other places in South America.

According to Murphy and Stanton (3), Victoria possesses characteristics of both common and red oats. It resembles Burt, Fulghum, and related varieties in its plant characters as well as in some of its kernel characters. The reddish-yellow color of the culms and lemmas indicates a relationship to *Avena byzantina* C. Koch. However, the florets separate in the same manner as in varieties of *A. sativa* L. The awns are very well developed, being mostly twisted and geniculate. Thus it is probable that the variety originated from a cross between the two species mentioned above.

SUSCEPTIBILITY OF VICTORIA

The Victoria variety has been tested with many races of loose and covered smut at the Brooklyn Botanic Garden, Brooklyn, N. Y., since 1932. The first indication of susceptibility was found in 1941, when a collection of loose smut, *Ustilago avenae* (Pers.) Rostr., on Fulghum made by T. R. Stanton in 1934 at Stillwater, Okla., was used for inoculation. In this series of experiments, Victoria gave

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[3]Figures in parenthesis refer to "Literature Cited", p. 1086.

43.8% infection. In the following years it has been inoculated with this collection, and frequently very high percentages of infection have been obtained. A brief report on this new race of loose smut, designated as A-30, has been published by Reed and Stanton (5).

In 1943, one of the writers (Wilds) found a severe smut infection in Victoria and in various hybrid selections from crosses in which Victoria was one of the parents in the oat breeding plots of the Coker's Pedigreed Seed Company, Hartsville, S. C. The smut, which was typical loose smut, *U. avenae*, was collected and sent to the Brooklyn Botanic Garden, where further tests have been made. The results indicate that a race distinct from A-30 was present and is here designated A-31.

The present paper includes the results of the extensive investigations conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, the Coker's Pedigreed Seed Company, and the Brooklyn Botanic Garden. In the course of the experiments a large number of oat varieties and selections from many crosses were inoculated with both races A-30 and A-31 of loose smut. The methods of inoculation were the same as those previously described by Reed (4).

REACTION OF SELECTIONS FROM LEE-VICTORIA CROSSES TO PHYSIOLOGIC RACES A-30 AND A-31

A cross between Lee and Victoria was made in 1931. The Lee variety was developed from a cross between Winter Turf and Aurora. Lee is highly susceptible to practically all known races of both loose and covered smuts, under favorable conditions, giving very high percentages of infection. Victoria, in contrast, is resistant to all known races of covered smut, as well as to many races of loose smut, with the exception of A-30, A-31,[4] and the so-called "Victoria race" reported on Fultex in Kansas by Hansing, Heyne, and Stanton (1).

The first generation plant of the hybrid Lee×Victoria was grown at the Aberdeen Substation, Aberdeen, Idaho, in 1931, and the second generation at the same station in 1932. In 1933, selected F_3 generations were grown at several state experiment stations, including tests in special chambers at Ames, Iowa, for cold resistance. From these various sources, selections were made from the F_3 and later generations, which selections have resulted in a number of similar named varieties, such as Lega, Lelina, and Letoria. Some of the most important selections, however, were made by the Coker's Pedigreed Seed Company from material first received in 1934, giving rise to their variety "Stanton".

The data obtained by inoculating the named varieties and certain closely related selections are of interest. The ten named varieties developed from selections of the original cross, including DeSoto, Florilee, Lega, Lelate, Lelina, Lenoir, Letoria, Leroy, Levic, and Stanton (three strains) when tested at the Brooklyn Botanic Garden with A-30, gave infections ranging from 56 to 100%. In the same

[4]The physiologic race of loose smut designated by Reed and Stanton (5) as A-30 has been given No. A-15 by Holton and Rodenhiser (2). In their system of numbering, our No. A-31 would become their A-16.

experiments Lee gave 100% infection, Victoria 87%, and Klein Victoria, a closely related strain, 85%.

When inoculated with A–31, Lee had a 96% infection and Victoria 80% at the Brooklyn Botanic Garden; whereas at Hartsville, Lee had 47% infection and Victoria 26%. The same ten named varieties mentioned above also were inoculated with A–31 at the Botanic Garden, where the percentage of infection ranged from 40 to 96%. Four of these varieties, DeSoto, Lega, Lelina, and Letoria, were grown at Hartsville and had infections ranging from 70 to 90%, whereas strains 1, 2, and 3 of the variety Stanton gave infections ranging from 61 to 91%. Twelve additional selections of the Stanton type were inoculated with A–30 at Brooklyn and two others with A–31 at Brooklyn and Hartsville. All proved to be highly susceptible.

The Division of Cereal Crops and Diseases has given C. I. accession numbers to 44 additional selections from the Lee-Victoria cross, all of which were inoculated with A–30 and many with A–31. With A–30, the infection ranged from 5 to 90% and with A–31 from 48 to 96%.

Among these 44 selections, one group representing 23 that were closely related to Lega, Lelina, and Letoria, showed a range in infection of from 5 to 79% when inoculated with A–30. The one selection (C.I. 3969) innoculated with A–31 was infected 76%.

A second group of 10 selections made by C. Roy Adair at Stuttgart, Ark., ranged in infection from 52 to 84% when inoculated with A–30 and from 64 to 96% when inoculated with A–31. A third group of 10 Coker selections made from mass seed of the Lee-Victoria cross at Hartsville, S. C., ranged in infection from 44 to 80% and from 48 to 84% infection when inoculated with A–30 and A–31, respectively. One lone selection, Tifton 8110 (C. I. 3922), was infected 100% when inoculated with A–30 and 72% when inoculated with A–31. Thus, nearly all varieties and selections originating from the Lee-Victoria cross were highly susceptible to the new races A–30 and A–31.

REACTION OF SELECTIONS FROM VICTORIA-FULGRAIN CROSS TO PHYSIOLOGIC RACES A–30 AND A–31

The Fulgrain variety originating from a cross between the variety Big Boy (Norton No. 20–93) and Navarro was made by Wilds in 1925. Selections from this cross were made by Wilds that gave rise to Fulgrain Strains 1, 2, and 3. These smut-resistant strains were distributed extensively by the Coker's Pedigreed Seed Company prior to 1941.

In 1933, Wilds crossed Victoria with Fulgrain Strain 1, from which cross Victorgrain and Fulgrain Strain 4 were selected. These were described and first distributed in 1940. In subsequent years, Victorgrain Strains 2, 3, 4, and 5 and Fulgrain Strains 5, 6, and 7 were distributed.

Data were recorded on the relative infection with one or the other or both races for the original Victorgrain, 4 Victorgrain strains, 54 Victorgrain or Victorgrain-type selections, the original Fulgrain, 5 Fulgrain strains, 39 Fulgrain-type selections, and 44 selections from the Victoria-Fulgrain cross.

Victorgrain and Victorgrain Strains 1, 2, and 3 have given high percentages of infection with A–30 at Brooklyn and with A–31 at Brooklyn and Hartsville. In contrast, Strain 4 has been resistant to both races.

Coker's selections from Victorgrain, 32 in number, have mostly been very susceptible to A–30 at Brooklyn, although 6 were highly resistant. Twenty-one selections were tested at Brooklyn with A–31 and three of these proved to be resistant; the others were mostly very susceptible. Twelve of these selections were tested at Hartsville, giving results similar to those obtained at Brooklyn. The selections tested gave similar reactions to the two smut races.

Of the 16 Victorgrain-type selections tested with A–31 at Hartsville only, 15 gave no infection and 1 a mere trace. Six additional Victorgrain selections when inoculated with A–30 and A–31 at Brooklyn ranged from no infection to 64% and from no infection to 84%, respectively.

The original Fulgrain variety (C. I. 3253, B. B. G. 1141) is resistant to both physiologic races A–30 and A–31, and the selected Fulgrain Strains 3, 4, 5, 6, and 7 also were highly resistant to both races where tested.

Coker's Fulgrain selections, 24 in number, gave no infection with A–30 or A–31 at Brooklyn, except one with each race in which the percentage of smut was very low. The thirteen 1944 selections of this group and an additional group of 15 from the Coker's Pedigreed Seed Company grown at Hartsville also were all highly resistant.

From the Victoria-Fulgrain cross, 17 selections of Victorgrain type were grown at Hartsville in 1945, all giving negative results with A–31. In the same season 14 selections of the Fulgrain type were grown at Hartsville and only an occasional smutted plant was noted.

Altogether 38 selections from the Victoria × Fulgrain cross, which were not identified as Fulgrain or Victorgrain type, were grown at Brooklyn, having been inoculated with A–30. Nineteen of these gave more than 50% infection, a few 100%. Six of these were inoculated with A–31 at Brooklyn, 4 being infected more than 50%, and two 17 and 20%, respectively. At Hartsville these selections showed comparable results except for one selection which gave 84% at Brooklyn and 23% at Hartsville. Of six other similar selections grown at Hartsville, five gave negative results and one 7% infection.

REACTION OF SELECTIONS FROM VARIOUS CROSSES INVOLVING VICTORIA, BOND, OR OTHER VARIETIES INOCULATED WITH A–30 AND A–31

A large number of selections and named varieties from many different oat crosses have been tested in these experiments, the data for which are recorded in Table 1.

With both races A–30 and A–31, many combinations have shown high resistance, as follows:

(Green Russian-Bond) × (Lee-Victoria), two selections
(Markton-Fulghum) × (Victoria-Fulgrain), one selection

TABLE 1.—*Reaction of selections from various crosses involving Victoria, Bond, and other varieties when inoculated with physiologic races A-30 and A-31 of loose smut at Brooklyn, N. Y., and Hartsville, S. C.*

Variety or selection	C.I. No.*	B.B.G. No.†	Percentage of plants infected with		
			A-30	A-31	
			Brooklyn	Brooklyn	Hartsville
(Green Russian-Bond)×(Lee-Victoria):					
Coker 44-42	—	1500	0	0	6
Coker 44-43	—	1501	0	0	7
(Markton-Fulghum) × (Victoria-Fulgrain):					
Coker 42-59	—	1365	0	0	–
Nortex×Victoria:					
Carolina Red	4313	1539	0	0	0
Ranger	3417	1213	0	0	0
Rangler	3733	1215	0	0	0
Rustler	3754	1214	0	0	0
Tex. 11-34-103	3534	1211	0	0	–
Tex. 11-35-41	3535	1212	0	0	–
Norton×Victoria:					
Coker 40-28	3943	1189	0	4	–
Coker 41-40	4436	1498	0	0	0
Alber×Bond:					
Camellia	4079	1280	0	0	–
Alber×Coker 32-1:					
Coker 41-12	—	1295	4	4	–
Bond×(Victoria-Fulgrain):					
Coker 41-4	—	1499	0	0	0
Coker 32-1×Capa:					
Coker 40-27	3942	1188	0	0	–
Coker 41-43	—	1306	0	0	–
Iowa D69×Bond:					
Benton	3910	1537	16	0	–
Clinton	3971	1541	0	0	–
Sac	3907	1546	15	12	–
Selection	3663	1281	0	0	–
Cherokee	3846	1282	0	0	–
Fulgrain×Capa:					
Coker 42-40	—	1346	0	0	–
Victoria×Richland:					
Boone	3305	1125	16	0	–
Cedar	3314	1134	5	8	–
Control	3603	1159	4	4	–
Tama	3502	1173	0	0	–
Vicland	3611	1176	18	0	–
(Victoria-Richland)×Fulton type:					
Neosho	4141	1543	0	0	–
Osage	3991	1544	0	0	–
Ventura	3989	1549	0	0	–

*Accession number of the Division of Cereal Crops and Diseases.
†Brooklyn Botanic Garden number.

TABLE 1.—*Continued.*

Variety or selection	C.I. No.*	B.B.G. No.†	Percentage of plants infected with A-30 Brooklyn	A-31 Brooklyn	A-31 Hartsville
Red Rustproof × (Victoria-Richland):					
Verde	4312	1550	0	0	–
Tenn. 090 (Winter Fulghum) × Victoria:					
Coker 43-54	——	1515	35	35	31
Coker 43-58	——	1516	75	75	52
Fulghum × Victoria:					
Fultex	3531	1208	76	92	59
Quincy Red (Quincy 1)	4077	1545	25	12	–
Selection	3747	1207	0	16	–
Selection (Kans. 6161)	3967	1284	70	60	–
Hairy Culberson × Victoria:					
Selection	3409	1272	88	80	–
Selection	3401	1273	70	80	–
Selection	3413	1276	56	72	–
Selection	3415	1278	71	64	–
Selection	3416	1279	68	60	–
(Victoria-Richland) × (Lee-Victoria):					
Coker 43-52	——	1513	80	100	92
Coker 43-53	——	1514	60	–	35
Fulghum × Bond:					
Selection (Arkansas)	4076	1283	20	5	–
Lee × Bond:					
Selection 175-15	3695	1223	27	20	–
(Bond-Coker Norton) × Victoria:					
Coker 45-59	——	——	–	–	0
(Green Russian-Bond) × (Victoria-Richland):					
Coker 45-69	——	——	–	–	0
(Red Rustproof-Red Rust proof) × [(Victoria-Richland) × Victorgrain]:					
Coker 45-63	——	——	–	–	1
(Victorgrain-Red Rustproof) × [Red Rustproof × (Victoria-Richland)]:					
Coker 45-62	——	——	–	–	0
(Iowa D69-Bond) × Fultex:					
Coker 45-61	——	——	–	–	0
(Green Russian-Bond) × Coker 32-1:					
Coker 45-55	——	——	–	–	7
Lee × (Bond-Iogold):					
Coker 45-68	——	——	–	–	3

*Accession number of the Division of Cereal Crops and Diseases.
†Brooklyn Botanic Garden number.

TABLE 1.—*Concluded.*

Variety or selection	C.I. No.*	B.B.G. No.†	Percentage of plants infected with		
			A-30	A-31	
			Brooklyn	Brooklyn	Hartsville
Tennessee 1922 × (Bond-Iogold):					
Coker 45–67	——	——	–	–	2
(Victoria-Richland) × Coker 32–1:					
Coker 45–56	——	——	–	–	0
Coker 45–70	——	——	–	–	1
(Victoria-Richland) × (Victoria-Fulgrain):					
Coker 45–41	——	——	–	–	3
Tennex × Bond:					
Coker 45–66	——	——	–	–	67
(Iowa D69-Bond) × Iowa Winter 8:					
Coker 45–60	——	——	–	–	36
Iowa Winter 10 × (Bond-Double Cross):					
Coker 45–34	——	——	–	–	20
Coker 45–35	——	——	–	–	26
Coker 45–64	——	——	–	–	38
Coker 45–65	——	——	–	–	0

*Accession number of the Division of Cereal Crops and Diseases.
†Brooklyn Botanic Garden number.

Nortex × Victoria, four varieties, *viz.*, Carolina Red, Ranger, Rangler, and Rustler, and two selections, C. I. Nos. 3534 and 3535

Alber × Coker 32–1, one selection, Coker 41–12

Norton × Victoria, two selections, C. I. Nos. 3943 and 4436

Alber × Bond, one variety, Camellia

Bond × (Victoria-Fulgrain), one selection, Coker 41–4

Capa × Coker 32–1, two Coker selections

Iowa D69 × Bond, four varieties, *viz.*, Benton, Clinton, Cherokee and Sac, and one selection, C. I. No. 3663

Fulgrain × Capa, one selection, Coker 42–40

Victoria × Richland, five varieties, *viz.*, Boone, Cedar, Control, Tama, and Vicland, and 14 unnamed sister selections, including those accessioned as C. I. Nos. 3301 to 3304, 3306 to 3313, 3315 and 3317

(Victoria-Richland) × Fulton type, three varieties, *viz.*, Neosho, Osage, and Ventura

Red Rustproof[2] × (Victoria-Richland), one variety, Verde

In contrast with the above, the following selections and varieties, with some exceptions, proved to be very susceptible:

Tennessee 090 (Winter Fulghum) × Victoria, 16 Coker selections (Only two, however, were tested with both races at both

Brooklyn and Hartsville. Of 6 other selections tested only at Hartsville with A–31, four gave no infection or were highly resistant and the remaining two were moderately resistant.)

Fulghum×Victoria, two varieties, Fultex and Quincy Red (Quincy 1) and two selections

Hairy Culberson×Victoria, eight selections of which three were tested only with A–30 at Brooklyn (data not given in Table 1)

(Victoria-Richland)×(Lee-Victoria), 12 Coker selections (data on only two selections given in Table 1)

Moderate infection was obtained with varieties and selections from the following:

Fulghum×Bond, one selection (Arkansas)

Lee×Bond, one selection

At Hartsville a few additional selections were grown from various crosses inoculated with A-31. The following were resistant:

(Bond-Coker Norton)×Victoria, one selection, Coker 45–59

(Green Russian-Bond)×(Victoria-Richland), one selection, Coker 45–69

(Red Rustproof-Red Rustproof)×[(Victoria-Richland)×Victorgrain], one selection, Coker 45–63

(Victorgrain-Red Rustproof)×[(Red Rustproof)×(Victoria-Richland)], one selection, Coker 45–62

(Iowa D69-Bond)×Fultex, one selection, Coker 45–61

(Green Russian-Bond)×Coker 32–1, one selection, Coker 45–55

Lee×(Bond-Iogold), one selection, Coker 45–68

Tennessee 1922×(Bond-Iogold), one selection, Coker 45–67

(Victoria-Richland)×Coker 32–1, two Coker selections

(Victoria-Richland)×(Victoria-Fulgrain), seven Coker selections, all showing no infection except Coker 45–41 when tested at Hartsville only with A–31

Tennex×Bond, Coker selection 45–66, highly susceptible

(Iowa D69-Bond)×Iowa Winter 8, one selection, Coker 45–60

Iowa Winter 10×(Bond-Double Cross), four Coker selections, three moderately susceptible and one showing no infection

REACTION OF TESTER OAT VARIETIES FOR OAT SMUT RACES, TOGETHER WITH SOME MISCELLANEOUS VARIETIES INOCULATED WITH PHYSIOLOGIC RACES A–30 AND A–31

The data for many older varieties of oats as well as more recently developed ones inoculated with A–30 and A–31 are given in Table 2. It will be noted that 28 of these varieties were highly resistant to both A–30 and A–31, although some of them gave low percentages of infection. In contrast, three varieties, Black Norway, Canadian, and Fulghum, gave comparatively high percentages of infection with both smuts. It is interesting to note that Canadian, a variety highly susceptible to most races, gave 100% infection with A–31 but only 48% with A–30.

Seven varieties, Danish, Danish Island, Gothland, Joanette, Liberty, Monarch, and Rossman, proved to be susceptible to A–30 and resistant to A–31. Black Diamond gave 53% infection with

A-30 and only 25% with A-31. Early Champion reacted in a similar way, giving 67% infection with A-30 and only 17% with A-31.

In contrast with these, four varieties, Bicknell, Hull-less, Traveler, and Trisperma, were susceptible to A-31 and resistant to A-30. It is

TABLE 2.—*Reaction of tester oat varieties for oat smuts, together with some miscellaneous oat varieties, when inoculated with physiologic races A-30 and A-31 at Brooklyn, N. Y.*

Variety or selection	C.I. No.*	B.B.G. No.†	Percentage of plants infected with	
			A-30	A-31
Algeribee	4228	1529	0	0
Bannock	2592	1146	0	0
Bicknell	3499	341	5	100
Black Diamond	1878	116	53	25
Black Mesdag	1877	70	0	0
Black Norway	1874	118	58	67
Bond	2733	1010	3	4
Canadian	1625	119	48	100
Cornellian	1242	928	0	4
Danish	1669	309	82	0
Danish Island	3210	149	68	4
Early Champion	1866	150	67	17
Fulghum	708	1000	63	52
Golden Rustproof	1751	316	13	0
Gothland	1898	152	47	8
Green Mountain	1892	110	0	0
Hancock	3346	1164	0	0
Hull-less	3007	30	0	95
Huron	3756	1165	0	0
Iogold	2329	930	0	0
Joanette	1762	187	43	0
Klein Capa	4232	1533	0	0
Klein Mar	4233	1534	0	5
La Prevision 13	4235	1536	0	0
Lenroc	3205	1166	13	0
Liberty (Hull-less)	845	292	81	0
Marion	3247	1144	0	0
Markton	2053	732	0	0
Monarch	1876	161	86	6
Monarch Selection	1879	162	0	0
Nakota (Hull-less)	2883	1168	0	0
Navarro	966	939	0	0
Palestine×Dawn	4229	1530	8	8
Palestine×Dawn	4230	1531	0	0
Palestine×Dawn	4231	1532	5	8
Red Rustproof (Appler)	1815	999	0	0
Rossman	1688	322	63	0
Scottish Chief	1901	124	0	0
Seizure	1609	246	12	0
Traveler	4206	1548	0	88
Trisperma	1776	64	0	100
Uton	3141	1160	0	0
Vanguard No. 7	3837	1175	3	0
Victor	1875	126	17	28
Victory	560	1177	0	0

*Accession number of the Division of Cereal Crops and Diseases.
†Brooklyn Botanic Garden number.

interesting to note that varieties such as Seizure and Victor, which are very susceptible to most races of loose smut, have given comparatively low percentages of infection. Further, the varieties Green Mountain, Scottish Chief, and Victory, usually very susceptible to other races, have given no infection with A–30 and A–31.

The two races A–30 and A–31 may be readily separated on the basis of their reaction to the tester varieties shown in Table 3.

TABLE 3.—*Reaction of tester varieties to races A-30 and A-31.*

Variety	C.I. No.	Smut percentages with	
		A-30	A-31
Danish	1669	82	0
Danish Island	3210	68	4
Gothland	1898	47	8
Joanette	1762	43	0
Liberty	845	81	0
Monarch	1876	86	6
Rossman	1688	63	0
Bicknell	3499	5	100
Hull-less	3007	0	95
Traveler	4206	0	88
Trisperma	1776	0	100

CONCLUSIONS

The two races of loose smut, A–30 and A–31, attack a large number of varieties and selections of oats, many of which have been considered smut resistant. The data obtained indicate that a large number of these are highly susceptible to races A–30 and A–31. A few varieties resistant to these races are susceptible to the newly discovered race in Kansas (1).

Many of the varieties and selections tested involve the Red Rustproof group of oats. Most of these are resistant to races A–30 and A–31. It is possible, however, that some or all of them may be susceptible to the Red Rustproof races of loose smut.

It is interesting that none of the known races of covered smut, *Ustilago kolleri*, infects the newly developed varieties and selections from the Lee-Victoria crosses. It is rather surprising that some of them have not been susceptible, since the variety Lee is attacked by many of these races.

LITERATURE CITED

1. HANSING, E. D., HEYNE, E. G., and STANTON, T. R. Reaction of oat varieties and selections to four races of loose smut. Phytopath., 36:433–445. 1946.
2. HOLTON, C. S., and RODENHISER, H. A. Physiologic specialization in the oat smut fungi with special reference to breeding oats for smut resistance. In press in USDA Tech. Bul.
3. MURPHY, H. C., and STANTON, T. R. Oat varieties highly resistant to crown rust. Jour. Amer. Soc. Agron., 22:573–574. 1930.
4. REED, GEORGE M. Physiologic races of oat smuts. Amer. Jour. Bot., 27:135–143. 1940.

5. ——————., and STANTON, T. R. Susceptibility of Lee × Victoria oat selections to loose smut. Phytopath., 32:100–102. 1942.

6. STANTON, T. R., and MURPHY, H. C. Oat varieties highly resistant to crown rust and their probable agronomic value. Jour. Amer. Soc. Agron., 25:674–683. 1933.

The Use of Frequency Distributions of Weather Factors in Agronomic Practices[1]

JAY T. WAKELEY AND J. A. RIGNEY[2]

WEATHER is one of the greatest contributors to crop failure. Yet knowledge of this factor lags far behind the abundance of information available concerning adaptation of crop varieties, fertilizer applications, and cultural practices. There is need for such information as the frequency of occurrence of extended dry periods, extended wet periods, temperature-precipitation relationships at specific stages in the development of a crop, and many others. If this information could be obtained by short intervals of time, it would be very valuable to the farmer. The agronomist would be in a position to recommend certain changes in cultural practices which would more certainly assure farmers of a profitable yield and an improved quality. Too, these data could be used to characterize the climate of a given region in such a manner as to guide the plant geneticist in developing new varieties which are "tailor-made" to fit the climatic peculiarities of that region. Through a comparison of the probable weather conditions to be expected and the requirements of the crop, the recommendation of specific crops and the timing of cultural practices can be more scientifically made. The needs and applications of these types of data are clear; the problem is to obtain them in a readily usable form.

The effects of climatic factors are so interrelated that all available factors should be summarized to give a complete climatic description. Furthermore, the form of the summary should be such that variations in interval of time may be made readily, and coincident frequencies of various factors may be obtained. This is a very costly and time-consuming job if it must be done by hand tabulation. This tedious method would also necessitate complete repetition of the process if, at a later date, it were decided that a frequency tabulation of a slightly different sort was more desirable. Therefore, if data are punched on cards, rapid compilation of frequency distribution can be attained by use of the card sorter and tabulator. Once the data are on cards, the operator can produce any frequency distribution that might be requested from time to time merely by running the cards through the sorter again.

In this paper are presented some examples of the types of distributions that may be obtained and uses that can be made of them. The data used were for the Caroleen, N. C., station, in the south west piedmont section of the state. This is one of the most intensive homo-

[1]Contribution from the Institute of Statistics, Raleigh, N. C. Taken from a progress report (May 1947) on a cooperative project between the U. S. Weather Bureau, Washington, D. C., and the Institute entitled "Climatic Factors Affecting Plant Growth and Crop Production in the Southwest Piedmont of North Carolina". Published with the approval of the director of the North Carolina Agricultural Experiment Station as Journal Series No. 267. Received for publication September 4, 1947.

[2]Graduate Assistant and Plant Science Statistician of the Institute of Statistics, respectively.

geneous cotton-producing areas of the state. The station provided 39 years of daily records which may be considered a sufficiently long period to give the distributions some stability.

Since temperature and precipitation are perhaps the most important climatic factors with respect to crop production,[3] only these two factors have been used in this paper. However, U. S. Weather Bureau stations have available, in addition, data on humidity, evaporation, wind, and other possibly important variables. In order to obtain information concerning short-period variations in mean temperature, precipitation, cloudiness, and frost-free periods, the data were broken down into 10-day periods throughout the year, beginning on 1 January. The 29th day of February was omitted except in duration frequencies in order to make the periods exactly comparable from year to year. Temperature data were arbitrarily summarized in classes of 3° Farhenheit.

COTTON

Cotton culture has long continued to be a success in the area under study. The region ranks high in North Carolina[4] in production and quality of the produce. Included in many diverse explanations for this success are freedom from boll weevil, the relatively high potash content of the soil, and the intensity and refinement of cultivation practices. These factors are undoubtedly influenced by climate.

There are, in general, three stages in the growth and production of cotton during which different types of weather are critical *viz.*, (a) seeding and emergence, (b) fruit bud formation and boll setting, and (c) harvest.

It is recognized that during germination excessive rainfall, coupled with cool weather, increases the prevalence of seed decay. On the other hand, dry weather, especially when accompanied by high temperatures, retards and reduces germination. Once the seedlings emerge, too much rain tends to produce shallow-rooted plants which are less capable of enduring subsequent droughts. These, and other conditions, are well known to be detrimental at this stage of growth. Thus it appears that if high moisture prevails it must be accompanied by warm temperatures to be conducive to good seed germination. Fig. 1 shows the frequency of occurrence of periods of 10 days in which at least 5 days were 65°F or over and in which at least 2 days had 0.30 inch or more of rain. The season of planting and emergence in this particular area ranges from late April to mid-June. Fig. 1 indicates that the probability of hitting the above conditions is very low in the early part of this period but increases rapidly to 45% by the first of June. Plantings made the middle of May can be expected to enjoy these favorable conditions two years out of five.

During the fruiting stage, when shedding of the squares, flowers, and young bolls is so important, soil moisture conditions have more bearing on development than any other single factor. The water requirement of the plant is at a maximum, and a drought would prove

[3]KLAGES, K. H. W. Ecological Crop Geography. New York: The McMillan Co. 1942. (Chapter VI.)

[4]North Carolina Agricultural Statistics. Number 88, 1945 Annual Issue.

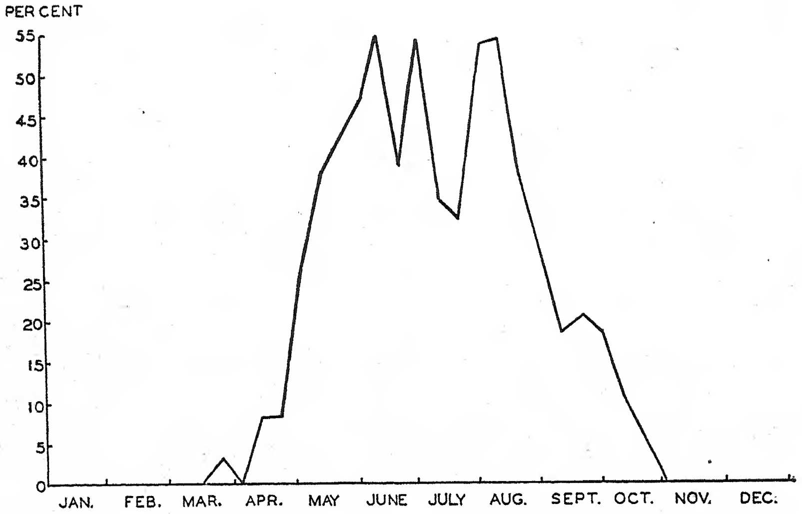


FIG. 1.—Percentage distribution of years having within each 10-day period 2 or more days with >0.29 inch of precipitation and also with at least 5 days with mean temperature >65°F.

most injurious. Figs. 2 and 3 present graphically the probabilities of no rain for 10 and 20 consecutive days, respectively. The low frequency of 10- and 20-day droughts during the average period of fruiting (20 June to 10 August) are strikingly evident. The average occurrence of a 10-day drought is less than 10%, or less than 1 year in every 10.

These same graphs may be considered in an evaluation of conditions existing during the picking season. Precipitation not only interferes with picking operations, but also damages the fibers in the open bolls. The relatively high frequency of droughts during the period from early September through late November indicates favorable picking conditions.

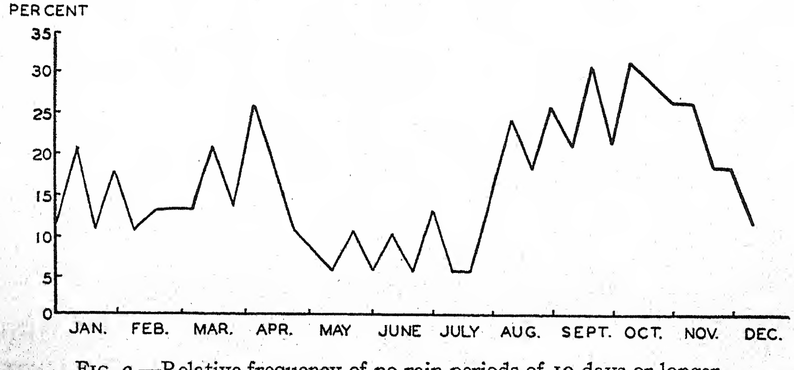


FIG. 2.—Relative frequency of no-rain periods of 10 days or longer.

CORN

Seasonal weather is also a powerful influence in determining the final yield of corn. One critical period in the development of corn occurs about six or seven weeks after planting when fertilizer materials are applied as a top dressing. A 3-week drought at this time would be sufficient to delay availability and materially reduce the effectiveness of the fertilizer. However, heavy rains also can be detrimental by causing surface washing and by leaching the fertilizer. Splitting the application may be resorted to if the rainfall is expected to be excessive for a single application. If it can be assumed that the frequency of rainfall of 0.30 to 0.99 inch is an index of favorable conditions for effective fertilization, the distribution of this quantity of precipitation may offer a basis for recommending a time of application. Fig. 4 presents the percentage of occurrence of 0.30 to 0.99 inch of precipitation throughout the year. The chart indicates that, for this area, it is suitable to apply a top dressing early in June. There appears to be an adequate chance of an optimum amount of rain for one complete application, since there is a chnace of about 1 day in 8 with the specified amount of precipitation.

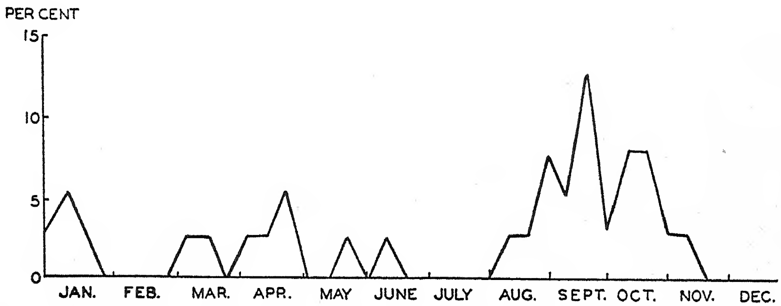


FIG. 3.—Relative frequency of no-rain periods of 20 days or longer.

CRIMSON CLOVER

Generally, weather is not a limiting influence on the growth of crimson clover in this region. However, it does become a decisive factor in the timing of related cultural practices and, in this manner, can exercise control over the initial stands produced and over the harvest.

Moisture is a critical factor in the selection of the time for seeding crimson clover. Very little moisture is required for seed germination, but a few dry days immediately following germination can greatly reduce the chances of getting a stand. Thus, the frequency of periods of no rainfall should prove important in the choice of seeding dates. The relative frequency of 6 or more consecutive days of no rain throughout the year is given in Fig. 5. Taking Fig. 5 at its face value, the last few days in August would be a recommended planting time in order to take advantage of the comparatively small likelihood of drought from date of seeding to mid-September. However, this point

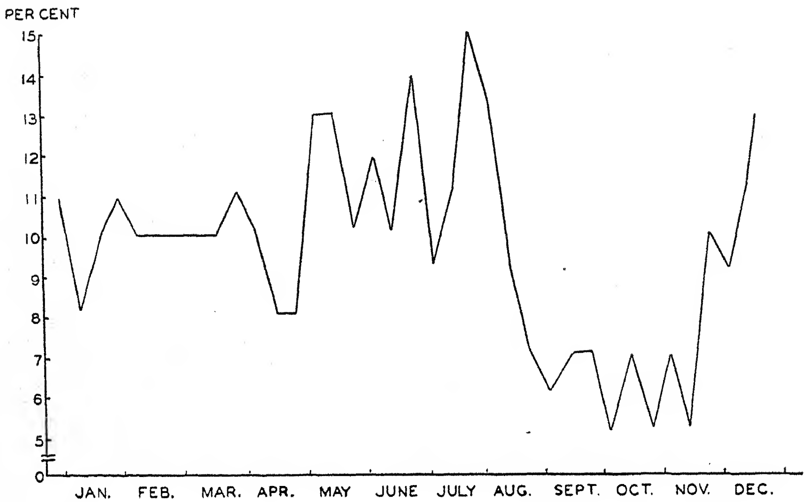


FIG. 4.—Relative frequency of daily precipitation of 0.30 to 0.99 inch.

of view might well be criticized from the standpoint of the significance of the differences between the 10-day periods of this season. Though the variation suggests the possibility that the same pattern of droughts may not hold over another 39 years, this is the best estimate available at present. Difficulties of this sort need not detract from the other uses that can be made of the data.

Other winter cover crops are used rather generally in the Southeast and date of seeding experiments indicate the desirability of early plantings. The feasibility of such practices may well be questioned for areas such as the one described here. Conditions which are favor-

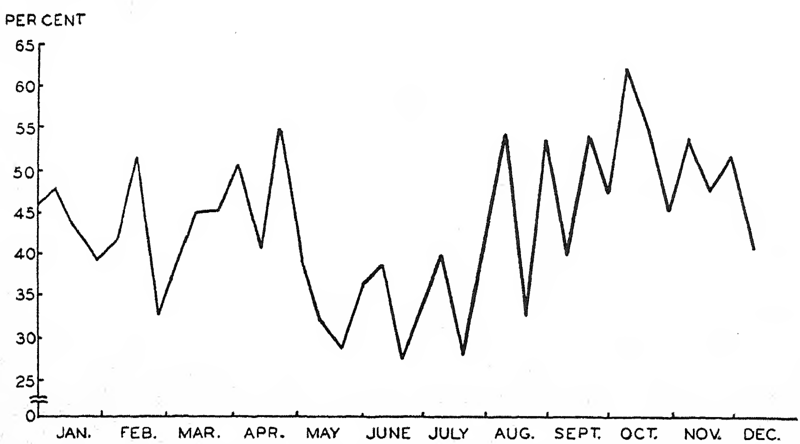


FIG. 5.—Relative frequency of no-rain periods of 6 days or longer.

able for cotton or corn harvest are not suitable for establishing cover crops and may explain the relatively low acreages of such crops in this area.

SUMMARY

If Weather Bureau records for individual stations are punched on cards, it is relatively easy to form distributions of weather factors which affect crop production. Examples are given of the types of distributions that may be obtained and some possible uses that can be made of them.

Notes

LIME INCREASES SORGO YIELDS

IN 1944, several experiments were started with various soil and fertilizer treatments in an effort to increase the yields of sorgo grown on Tifton fine sandy loam in southwestern Georgia where yields were unusually low. One of these experiments includes a comparison of lime and no lime with a uniform fertilizer treatment. Lime was added as hydrated lime equivalent to 1,000 pounds per acre of calcium oxide. Only the one application was made during the first year with sorgo grown continuously for 3 years. The lime was applied on the surface when the plants were about 3 inches high and mixed with the surface soil with a garden rake.

A large increase in yield was secured from the lime compared to no-lime treatment every year. Although the acre yields for both treatments were low, the mean increase of the lime treatment for the 3 years was about twice that of the no-lime treatment. In fact, the yield from the lime treatment was greater than that from any treatment used in the other experiments.

During the second and third year the effect of the lime on growth was easily noticeable as soon as the plants emerged and continued so until harvest. Further experiments are planned for additional information on rates and methods of application.

Sudan grass planted for hay on an adjoining field was similar in appearance to the unlimed sorgo crop. Several attempts to grow sudan grass seeded broadcast for hay production in this area have been failures.

These experiments with sorgo and observations on Sudan grass indicate strongly the need for lime before attempting growth of these crops in southwestern Georgia.—E. S. LYONS, *U. S. Sugar Plant Field Station, Cairo, Ga.*

A TRACTOR-MOUNTED TWO-ROW NURSERY PLANTER[1]

OBTAINING good stands of cotton is one of the major problems of cotton production in the El Paso Valley. Persistent spring winds dry the surface soil very rapidly, often before the seeds have sufficient time to germinate. Hence, it is necessary to plant as rapidly as possible when the soil moisture reaches the right stage. Inasmuch as severe crusting and caking occur unless the soil is properly handled, dragging immediately following planting to prepare a dust mulch or subsequent harrowing is usually essential. Conventional nursery planters and hoes have not proved satisfactory for planting cotton nursery plots at the El Paso Valley Experiment Station. Neither has it been found satisfactory to open a furrow, drop, and cover the seed. Since two-row cultivating equipment is used almost exclusively, it is necessary to space the rows accurately. Nursery plots are often located on cooperating farms in small sections of commercial fields, making it

[1]Contribution from the Texas Agricultural Experiment Station, Substation 17, Ysleta, Tex. Technical article No. 1065 of the Texas Agricultural Experiment Station.

desirable to follow, as nearly as possible, the same methods of planting used by the farmer and, furthermore, to plant as quickly as possible so as not to delay the usual farm operations. Accordingly, a two-row tractor-mounted planter (Fig. 1) using conventional runner and press wheel equipment was designed and built for space planting of progeny rows.

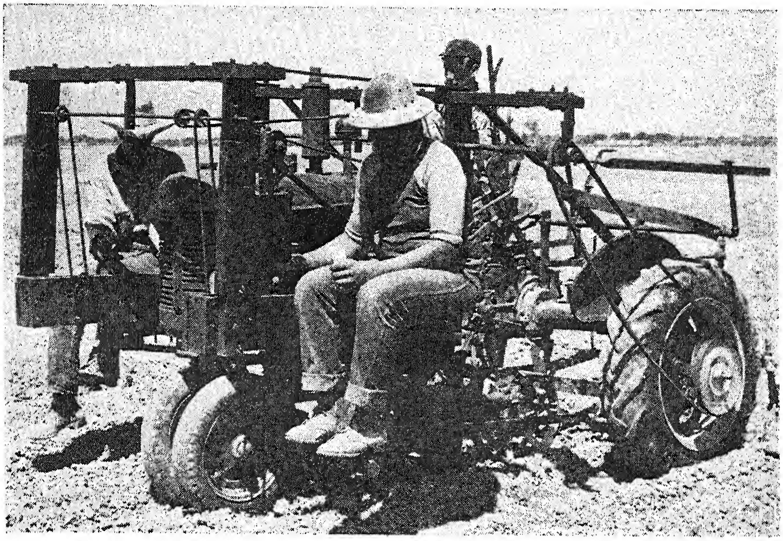


FIG. 1.—Two-row, tractor-mounted nursery planter.

The planter is mounted on a Farmall Model B tractor. A runner and press wheel designed for the Farmall HM–100 planter is fitted in the tool clamp on each side of the tractor. These are easily adjustable for common row widths. A wooden box or trough 51 inches long, 5 inches wide, and 7½ inches deep, with bottom open, is rigidly bolted to the main frame tool bar by means of short heavy iron bars. A ½ inch V-belt, 84 inches long, is mounted horizontally inside the trough on pulleys. Eight blasting cap cans (Fig. 2) are attached to the V-belt at regular intervals by 3/32 inch bolts. The belt is mounted so that the tops of these cans are just above the top of the wooden frame. The belt and cans are driven by a system of overhead belts mounted on two shafts. As the cans are moved backward on the belt and around the end pulley any seed in them is dropped in a funnel to which is attached a flexible metal spout leading to the runner.

Power is derived from a 12-inch V-belt pulley mounted on the rear wheel. A clutch is installed on the rear drive shaft, since it is necessary to throw the system out of gear or remove the main drive when not planting and when driving at a high speed. An implement seat is also mounted on the main frame tool bar just outside the wooden box. The seat is welded to a piece of angle iron which slips under, and is secured by, the gang beam head. Assistants ride on these seats and drop seed in the cans as they pass by.

The planter has been used successfully for space planting of cotton nurseries during the past 4 years. The size of the pulleys and the number of cans can be changed to secure the desired spacing. A 14-inch spacing for cotton, dropping approximately three seeds per hill has been used. At this close spacing some difficulty was experienced at first in getting the tractor to travel slowly enough to drop the seed accurately. However, one becomes adjusted to dropping the seed and little difficulty is encountered unless it is absolutely necessary to have the same number of seed in each hill. With wider spacing this is not a problem. The distance between hills often varies several inches. This difference in spacing is caused, apparently, by slight differences in time the seeds leave the cans and would be less serious with wider spacing. Another objection is that the seeds in a single hill scatter somewhat and do not remain bunched as might be desired. Acid-delinted seeds are used to facilitate dropping.

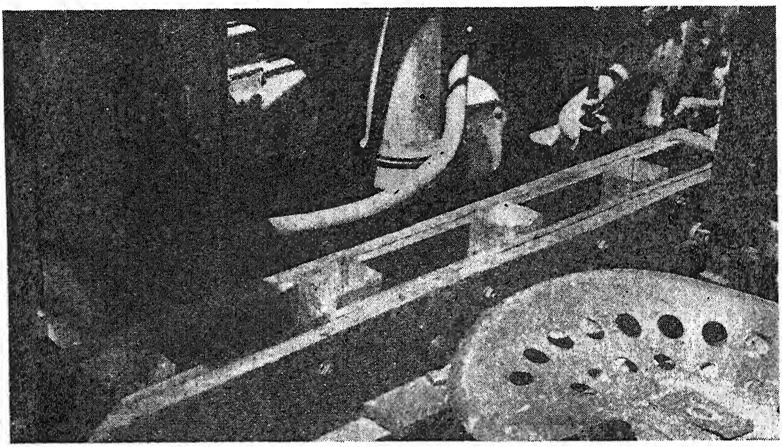


Fig. 2.—Cans used to secure spaced hill dropping.

In addition to cotton progeny rows the planter has been used to plant variety tests, both corn and cotton, and various large-seeded vegetables. Soybeans, field beans, and peas have been planted in drills by removing the belt and pouring the seed down the spout. The planter could be adapted for drilling rod plots by installing a rubber V-belt, such as found in rod nursery planters, in place of the belt with cans. The special pulleys necessary for this modification have, as yet, been unavailable.

In spite of the difficulties mentioned, which have been found to be of minor importance, the planter has been invaluable in handling space-planted progeny material. It provides a faster method of planting with a minimum amount of labor, gives exact row spacing for subsequent use of two-row implements, and facilitates planting under local conditions where crusting, caking, and drying of soil may be severe.—P. J. LYERLY, *Superintendent, Texas Agricultural Experiment Station, Substation No. 17, Ysleta, Tex.*, and JOSEPH BURRUS, *Machinist, retired.*

Book Reviews

DISEASES OF FIELD CROPS

By James G. Dickson. New York: McGraw-Hill Book Co., Inc. XII +429 pages, illus. 1947. $4.50.

THE book is a convenient reference outline on current information concerning diseases of field crops, including barley, corn, millet, oats, rice, rye, sorghum, Sudan grass, Johnson grass, sugarcane, wheat, forage grasses, alfalfa, sweetclover, clovers, soybeans, cotton, flax, and tobacco. A brief introduction is followed by a chapter on physiological anatomy of plant groups in relation to disease. A rather extended, but selective reference list is appended to each chapter.

Although the diseases are grouped and discussed in the main body of the text primarily from the standpoint of the particular crop affected, they are regrouped in the appendix on the basis of (1) the primary causal factor, a suggested list for class presentation on this basis; and (2) a list of the bacteria and fungi arranged by order and family. A comprehensive subject matter index enhances the usefulness of the book, both for the student and the research worker.

The book is well written, and although primarily intended for the student, it will undoubtedly prove a valuable condensed reference for plant pathologists and agronomists.—R. J. GARBER.

FOREST SOILS

By Harold J. Lutz and Robert F. Chandler. New York: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd. XI+514 pages, illus. 1946. $5.25.

THE authors state that, "This book was written with two objectives in mind. The first objective was to provide a textbook covering the fundamentals of soil science with applications of the science to forestry which would be suitable for use in the course in soils required of forestry students in American colleges and universities. The second objective was to provide a source of reference to reports of the more important researches on forest soils."

The reviewer feels that some of these objectives have been reasonably well fulfilled considering space limitations in a book of this size. An idea of the contents and sequence of subject matter are given by the chapter headings: Introductory; Soil-forming Minerals; Soil-forming Rocks; Disintegration and Decomposition of Minerals and Rocks; Forest-soil Organisms; The Organic Matter of Forest Soils; Nature and Properties of Soil Colloids; General Physical Properties of Forest Soils; The Water Relations of Soils, Particularly Forest Soils; General Chemical Properties of Forest Soils; Soil Formation; Forest Soil Classification; Soil Erosion and Forest-soil Deterioration.

As regards sequence, the reviewer feels that it would have been more logical to have placed Chapter 11, Soil Formation, nearer the beginning of the book, Also placing of Chapter 8, General Physical Properties of Forest Soils, near the beginning would have the advan-

tage of giving the student a general birds-eye view or conception of a soil at the start. This would help to stimulate the student's interest in what follows by making it easier to relate certain details to the soil as a whole.

Professional foresters, ecologists, and soil scientists will find this work a valuable source of forest soils knowledge, but practical foresters, nursery managers, rangers and others confronted with local problems will find it difficult to assimilate and apply the information as presented.

As a beginning text in soils, it would seem that some of the discussions, especially in relation to the scope of the book are rather advanced. For example, Chapters 2, 3, and 7 appear to be a little heavy for this type of text. Would it not have been better to have discussed, at least briefly, the function of the nutrient elements in plant growth than to have placed so much emphasis on minerals and rocks?

Because of the extensive list of references given at the end of each chapter, and the advanced and excellent nature of some of the discussions, it would seem that the book might serve better as a reference book than as a beginner's text; or it might be used quite advantageously for this latter purpose if supplemented with the needed lectures or discussions.—EMIL TRUOG.

BASIC BOTANY

By Fred W. Emerson. Philadelphia: The Blakiston Co. XI+372 pages, illus. 1947. $4.

IN writing this book which is intended as a text for an introductory course in botany, the author has approached the subject from the standpoint of the unifying influence of protoplasm. As stated in the preface, "physiology, anatomy, morphology, taxonomy, genetics, and ecology are all included, but not in an altogether traditional order. Leaves, stems, and roots are discussed in rather full detail, but as integral parts of the plant, which is a functional as well as a morphologic unit."

In so far as possible plants with which the student is likely to be familiar have been chosen for illustrative material. An effort has been made to instill in the student's mind the scientific approach to the solution of botanical problems. The book is profusely illustrated and contains an index.—R. J. GARBER.

NATURE AND PREVENTION OF PLANT DISEASES

By K. Starr Chester. Philadelphia: The Blakiston Co. Ed. 2. XI+525 pages, illus. 1947. $5.

THE book is intended as a text for college students and particularly for those students who take only the one course in plant pathology. Emphasis is placed on how to recognize, understand, and prevent plant diseases. To this end, the more important diseases of crops grown extensively in the United States are discussed together with the latest generally approved methods of control. The text contains a

number of illustrations and a glossary and index are appended.—R. J. GARBER.

THE ARBORETUMS AND BOTANICAL GARDENS OF NORTH AMERICA

By Donald Wyman. Waltham, Mass.: The Chronica Botanica Company. Stechert-Hafner, Inc. Chronica Botanica, Vol. 10, pages 395–498, illus. Paper covered. 1947. $1.50.

IN addition to listing the active arboretums and botanical gardens of North America, the author gives very briefly other pertinent information, such as chief functions including kind of plants featured, number of species and varieties, ownership, endowment, admission policy, greenhouse facilities, publications, library facilities, special events, the name of the Director, and the number of employees. Several pages are devoted to a discussion of planning, establishing, and maintaining arboretums or botanical gardens. An alphabetical index of the gardens described, together with a map showing location, small collections of special plants, and lists of both proposed and discontinued gardens conclude the booklet. Twenty-three plates showing old and new gardens are included. —R. J. GARBER.

SOILLESS GROWTH OF PLANTS

By Carleton Ellis and M. W. Swaney. New York: Reinhold Pub. Corp. Ed. 2. X+277 pages, illus. 1947. $4.75.

THIS revised edition of the earlier book published in 1938 is written for the practical hobbyist, the professional grower, and the student of hydroponics. The opening chapter is concerned with general plant physiology followed by chapters on types of soilless culture, water culture, sand culture, gravel culture, nutrient solution, control of nutrient solution, control of the plant culture, general plant culture, common detriments, special chemicals, and analyses of the nutrient solution. A selected list of references and an index are appended.—R. J. GARBER.

THE LAND AND WILDLIFE

By Edward H. Graham, New York: Oxford University Press. XIII+232 pages, illus. 1947. $4.

THIS is one of the rare books that discusses the problems of both land and wildlife with equal understanding and scientific soundness. It is written to make the point that most practical wildlife management is accomplished through good land use. The subject matter comprises the history of North America and its wildlife herittage, the various conservation practices applicable to the diverse wildlife habitats, such as swamps, ponds, stream banks, ditches, field borders, road sides, hedges, gulleys, crop land, pasture, woodlots, forests, and ranges. The three concluding chapters are devoted to the wildlife prospect, the cost and harvest, and the relation between wildlife, land, and people. The text is supplemented by a carefully selected bibliography.

Doctor Graham is deeply in love with his subject, and the book is written in such an interesting and persuasive manner that it overcomes one's tendency to criticize.

The basic idea of Graham, that misuse of land leads to depletion of wildlife, is unquestionably correct. At the same time, it seems that in numerous instances, the status of game may be at a very low level even though the land and its cover are in proper adjustment. With the exception of deer, this is a picture that is observed now on millions of acres of northern Wisconsin. Therefore, one of Graham's observations appears to bear directly to present-day conservation policy. He states, "The question is whether the carrying capacity of the land does not apply to those who hunt, as well as to that which is hunted."

Professional men, students of conservation, sportsmen, and land owners, all will find this book both useful and entertaining. The book is dedicated to the biologists of the Soil Conservation Service, who may be justly proud of this honor.—S. A. WILDE.

ELEMENTS OF FARM MANAGEMENT

By Jonh A. Hopkins. New York: Prentice-Hall, Inc. Ed. 3. XVI+524 pages, illus. 1947. $5.35.

THIS text is intended to help students and others acquire a working knowledge of the intricacies of farm management. The author approaches and develops the subject primarily from the standpoint of problems arising in farm operations rather than from the standpoint of principles in production economics, although certain fundamental principles are emphasized.

The book is divided into eight parts, general considerations, organizing the farm—the economic basis, the crop system, the livestock system, economizing labor and power, summary of the budget, current operations of the farm, and external relationships of the farm business, with appropriate chapters under each part. References are appended to each chapter and an index occupies the last pages.

The book is readable and undoubtedly will be of interest to agronomists.—R. J. GARBER.

AN INTRODUCTION TO AGRICULTURAL CHEMISTRY

By Norman M. Comber, H. Trefor Jones, and J. S. Willcox. New York: Longmans, Green & Co. VIII+315 pages, illus. 1947. $2.50.

THIS small yet very complete book is an admirably concise discussion of the major subjects which come under the broad definition of agricultural chemistry. The main chapters are "Soils", "Fertilizers", and "Animal Nutrition", but within these terms the authors deal with a wide variety of topics, such as plant nutrition, the chemistry of the major constitutents of plants and animals, the methods of field experimentation, etc. Especially thorough treatment is given to the formation, physical structure, and colloidal behavior of soils. The chapters on plant nutrition and on the determination of the availability in soils of various nutrients are excellent.

It is fascinating to compare a book of this sort with some of the early efforts in this field, as for instance, with Sir Humphry Davy's "Elements of Agricultural Chemistry" (1813). The progress in the chemistry of various constituents is impressive indeed, but the present status of our knowledge concerning the evaluation of dynamic factors, of catabolism and anabolism, and of the mechanisms of the transformations involved in both animal and especially plant life is somewhat disheartening. Agricultural chemistry has still a long way to go to have the answers to many of the most fundamental and important questions. A better understanding by the students of nature of the interrelation of various factors, so well emphasized by the authors, will help to attain the broader view needed for work on or with living materials.

The book is well organized, the style is clear and straight forward, and the index is very good. References are given by name only, without literature citations and without leads for more detailed information, a matter which might be corrected in later editions. This splendid little volume is recommended to both students and teachers. —Z. I. KERTESZ.

THE CHEMICAL COMPOSITION OF FOODS

By R. A. McCance and E. M. Widdowson. Brooklyn: Chemical Publishing Co., Inc. Ed. 2. 156 pages. 1947. $3.75.

THE evaluation of foods from the nutritional standpoint attained wide significance and appreciation in recent years. While in the past such information was used mostly in the dietetic and nutritional treatment of disease, now the food supplies of nations are often planned on the basis of tables such as given in this little book. The importance of this subject is indicated by the fact that one of the first actions taken by the Food and Agriculture Organization of the U. N. was to appoint a Committee on Caloric Conversion Factors and Food Conversion Tables.

The present volume gives the results of chemical analyses of British foods conducted under the sponsorship of the Medical Research Council. After describing the recipes used for prepared foods, the first part of the book gives the chemical composition of raw and prepared foods per 100 grams. The proportions of edible material, water, total N, purine N, protein, fat, and carbohydrates contents are given as well as the percentages of Na, K, Ca, Mg, Fe, Cu, P, S, and Cl. The calories per 100 grams and the acid-base balance values complete the tables.

The second part of the book repeats most of this information on the ounce basis. One would think that anyone who can make the difficult computations of caloric and other values of meals would be able to obtain the per ounce figures by multiplying the 100 gram values by 0.28. A table on the phytic acid phosphorus contents of some foods and a very thorough index complete the book.

Many agronomists will be disturbed by the use of a value obtained in a few analysis for such computations, but, alas, the alternatives are to analyze all foods as consumed or to have averages based on

many samples, neither answering the basic objections raised on account of the wide variations in food composition. There might be further doubts raised concerning the correctness of the caloric calculations where even the methods used by British workers and by nutritionists in the USA differ considerably. Many assumptions of questionable validity have to be made in such calculations.

It would be unfair to continue with the lists of objections, when to most of these no remedy can be offered. Some of the limitations of such tables are carefully set forth in the introduction. Useful as books of this sort are, they bring out forcefully the need for further research on the nutritional value of various foods and on the extent of variations which might occur in their composition. The latter is one point where the agronomist should be of great help to the chemist and nutritionist.

The organization of the tables is clear and the printing and binding of the book are excellent.—Z. I. KERTESZ.

CHEMICAL INSECT ATTRACTANTS AND REPELLENTS

By Vincent G. Dethier. Philadelphia and Toronto: The Blakiston Company. XV+289 pages, illus. 1947. $5.

MOST agronomists and plant breeders probably would not expect from the title that this book contains information important to them. This conclusion would be due to the fact that the title is somewhat incomplete. The author has discussed many physical and chemical characters of plants that act as repellents many of which are genetic so could be used in attempts to breed varieties that would have a high degree of immunity to some of our most serious insect pests.

Although the book is primarily for use by entomologists and biochemists, it is so interestingly written that it should appeal to any reader interested in scientific investigations. The general subject is one which has received much study by many investigators for more than fifty years, although the greater amount of such research has been made during the past thirty years.

Most of the results have been published in many foreign and domestic scientific journals so are not easily accessible to the reader who is interested in these phases of entomology. Doctor Dethier, in collecting and discussing the more important of these publications as well as presenting the results of his own investigations, has given also a comprehensive bibliography at the end of each chapter. This alone is a valuable aid to students of these problems.

It should not be inferred that the book is merely a review and discussion of the literature, both entomological and chemical, of this subject. The author states that he has made "an attempt to bridge the borderline between chemoreception and the broader aspects of '(insect)' behavior based upon it." In other words, he has made an effort to outline a scientific approach to the many problems of insect behavior in relation to physical and chemical attractants and repellents. In the preface the author states that, to a certain

extent, the book represents a theoretical study and that "it is neither a compilation of recipes for attractant and repellent substances nor a manual on insect control". While this may be true if the entire subject is considered, the reviewer finds presented much practical information and some recipes for baits that should be of value to many investigators. The book is well written and judiciously illustrated with 69 figures. The format and binding are excellent.—F. Z. HARTZELL.

TWO BLADES OF GRASS: A HISTORY OF SCIENTIFIC DEVELOPMENT IN THE U. S. DEPARTMENT OF AGRICULTURE

By T. Swann Harding. Norman, Okla.: University of Oklahoma Press. XV+352 pages, illus. 1947. $3.50.

HERE is a story-book of the U. S. Department of Agriculture written from within. The author first came to the Department in 1910, and for many years was editor of scientific publications in the Office of Information.

He writes of his acquaintances and associates without jealousy or eulogy, but with a straight-forward interest in their research and contributions. Emphasis is on the work not the men.

To attempt to parade the great names and works of the scientists that have come and gone through about 100 years, or of those that are still with us in an institution that today has a "staff of over 2,000 persons" at Agricultural Research Center alone is no mean task to crowd into a readable book. Harding has done a good job of it.

The book is really a history of agricultural research in America, because in one way or another some U. S. D. A. scientist was associated with most investigations whether done at the state experiment stations or at the nation's capitol city.

The U. S. D. A. started as a Division of Agriculture in two basement rooms in the Patent Office on May 15, 1862. Henry L. Ellsworth as Commissioner of Patents during 1836 and 1837 "at his own expense and without Congressional authorization, distributed seeds and plants gratuitously transmitted to him for the purpose". "He believed that a 10 per cent increase in wheat yields would provide the nation with an additional income from 15 to 20 million dollars annually". He asked Congress "to provide funds for collection and dissemination of agricultural seeds, plants, and statistics" continually to 1840 when Congress voted $1,000 for agricultural purposes. But free seed was not the answer that only scientific work could supply. Ultimately it became a disgrace, as certain heads of the Department declared, but did not cease until June 30, 1923".

Harding shows fairness in his dealings with the great names. Of Isaac Newton, the first Agricultural Commissioner, he says "Yet, however careless of ethical considerations Newton sometimes was in his clerical appointments his scientific appointments were uniformly men who had good professional standing and ranked with the best of their day".

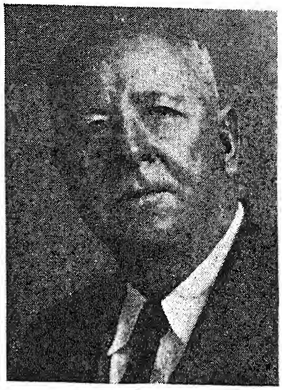
This history is fascinating and holds one's interest, because it is like a kaleidoscope. Names and achievements roll out of each chapter

hardly in an organized manner, but more as if one should go from door to door of the laboratories of the scientists with the author as the guide. Every stop is too short and your pet field is almost crowded out by the others.

The author knows his America, because he frequently points out the dollars returned to the nation from the long efforts of basic research. These values are impressive. The book is "worth-while-reading" for everybody.—GEORGE D. SCARSETH.

Fellows Elect

HUGH HAMMOND BENNETT



Hugh Hammond Bennett was born on a farm near Wadesboro, North Carolina, April 15, 1881. His undergraduate work was taken at the University of North Carolina. The honorary L.L.D. degree was conferred on him by his alma mater in 1936 and the honorary Sc.D. degree by Clemson College in 1937. Dr. Bennett's professional career began with his appointment as assistant chemist at the North Carolina Agricultural Experiment Station. Following this he became successively soil scientist and principal scientist, in charge of erosion investigations, in the Bureau of Plant Industry, U.S.D.A., director of the soil erosion service in the Department of Interior, and chief of the Soil Conservation Service of the U.S.D.A. During this period he was assigned to a variety of special duties in the Canal Zone, Alaska, Guatemala, South America and Cuba. He is the author of "Soils and Agriculture of the Southern States", "The Soils of Cuba", and "Soil Conservation". Of his many contributions to the cause of agriculture the most outstanding has been his accomplishment in the field of soil conservation. Except for his conscientious and aggressive efforts on behalf of the conservation of the soil resources of this country we would not have had the widespread awakening of public interest in the subject. As a result of his activities our whole philosophy with respect to land use has been changed for the better. Dr. Bennett is a human dynamo who moves all of those with whom he comes in contact to action in behalf of the cause which he so well represents.

HERBERT PRESS COOPER

Herbert Press Cooper was born on a farm near Ridgeway, South Carolina, February 18, 1887. His undergraduate work was taken at Clemson Agricultural College and his M.Sc. was obtained at the University of Wisconsin. The Ph.D. degree was conferred on him by Cornell University in 1922. Dr. Cooper's professional career began with an appointment as instructor in agronomy at Pennsylvania State College. Following this he became successively assistant professor in agronomy at Massachusetts State College, instructor in field crops at Cornell University, and assistant professor and professor of agronomy and dean and di-

rector at Clemson Agricultural College and the South Carolina Agricultural Experiment Station. Dr. Cooper's main scientific interests have been in relation to mineral nutrition of plants, soil fertility, ecology, and crop adaptation. His contributions on normal electrode and ionization potentials of the nutrient elements have been especially noteworthy and his concepts in this connection have aroused a great deal of interest. Dr. Cooper is a member of Sigma Xi, Phi Kappa Phi, and Alpha Zeta. He has long played a prominent part in the field of agronomy and is considered to be one of the leading soil scientists of the South. He is a quiet, unassuming man, but one whose enthusiasm for his work is highly contagious. His associates honor him for his unselfish devotion in the service of the agriculture of his state and region.

THOMAS HOMER GOODDING

Thomas Homer Goodding was born at Macon, Missouri, April 9, 1890. His undergraduate work was taken at the University of Nebraska where he also obtained his M.Sc. degree. The Ph.D. degree was conferred on him by Cornell University in 1933. Dr. Goodding's professional career began with his appointment as instructor in an agricultural high school at Gledden, Iowa. Following this he became successively assistant club leader in agricultural extension, assistant professor of agronomy, and professor of agronomy and supervisor of the short courses at the University of Nebraska. Dr. Goodding has devoted most of his life to the teaching profession and has gained a wide reputation among his students for his capacity to instruct and for his conscientious interest in their behalf. Notwithstanding his heavy teaching load and his supervisory work with the short courses, he has found time to do considerable research, his special interests being the adaptation of corn to the various soil types and the obtaining and development of legume crops that are adapted to the conditions on the Great Plains. He has been an active member of the Society. Dr. Goodding has the type of inspirational personality that appeals to young men and many of those who have come under his guiding hand now occupy positions of great importance in the field of scientific agriculture.

ROBERT EARL KARPER

Robert Earl Karper was born on a farm near Chambersburg, Pennsylvania, October 9, 1888. His undergraduate work was taken at Kansas State College and his M.Sc. degree was obtained at Texas Agricultural and Mechanical College. Mr. Karper's professional career began as assistant agronomist at the Oklahoma Agricultural and Mechanical College. Following this he became successively superintendent of Experiment Substation No. 8, agronomist, and vice-director of the Texas Agricultural Experiment Station. Through the research efforts of Mr. Karper and his coworkers the grain sorghums of Texas have been remade to become a major crop. This was accomplished by the application of basic genetic principles to the developments of types of sorghums that can be harvested with combines. Higher yield, better industrial quality, and greater resistance to disease have been incorporated into these combine sorghums. Further studies are being made of the interrelations of genetics and physiology in sorghums in an attempt to utilize hybrid vigor to the end that the yields are raised an additional 25 to 30 per cent. Mr. Karper is a member of Sigma Xi and Phi Kappa Phi. The list of his scientific papers includes a number that merit a high place in the literature of his field of endeavor.

BEN ADOLPH MADSON

Ben Adolph Madson was born on a farm near Jewell Junction, Iowa, March 19, 1887. His undergraduate work was taken at Iowa State College. Later he studied at the University of Illinois and at the University of Chicago. Professor Madson's professional career began with his appointment as assistant chemist at the Iowa Agricultural Experiment Station. Following this he became successively assistant professor and associate professor of agronomy at the University of California College of Agriculture at Davis, and chief of the division, professor, and agronomist at the Agricultural Experiment Station, also at Davis. His primary researches have been in relation to plant physiology, organic nutrition of plants, and the improvement of legumes and grasses. He has a long list of important publications to his credit. He has been responsible for many improvements in agricultural practice in his state. Professor Madson has played an active part in the affairs of

the Western Branch of the Society. He is a member of Sigma Xi, Alpha Zeta, and Gamma Delta. He is a man of substance who brings to bear a well-trained mind in the solution of the crop problems with which his state is faced.

CHARLES EDMUND MARSHALL

Charles Edmund Marshall was born at Bredbury, Cheshire, England, January 9, 1903. His undergraduate work was taken at Manchester University where he also obtained an M.Sc. degree. The Ph.D. degree was conferred on him by the University of London in 1927. He subsequently studied under the direction of Professor G. Wiegner of the Eidg. Tech. Hochschule, at Zurich, Switzerland. Dr. Marshall's professional career began with his appointment to the staff of the Rothamsted Experimental Station where he worked on the chemistry of soil humic matter. Following this he was successively assistant lecturer in agricultural chemistry at the University of Leeds and associate professor and professor of soils at the University of Missouri. His scientific work has had to do with the mineralogy and colloid chemistry of clays, mineralogical and chemical studies of soil-formation processes, membrane electrodes and electrochemistry of clays, and soils in relation to plant nutrition. Dr. Marshall has played an important part in the activities of the American Society of Agronomy. He is a member of Sigma Xi and Gamma Sigma Delta. He has brought with him from abroad an excellent preparatory training for his work, which is being applied to excellent advantage in the more technical phases of soil research. He has made an important place for himself, both personally and scientifically.

WILLIAM THOMAS McGEORGE

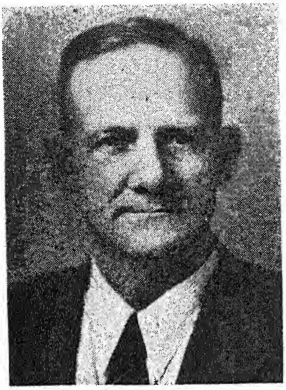
William Thomas McGeorge was born at Rosedal, Kansas, July 27, 1886. His undergraduate work was taken at the University of Kansas. He obtained his M.Sc. from George Washington University. Professor McGeorge's professional career began with his appointment as chemist for Swift & Co., at Kansas City. Following this he became successively chemist at the Hawaiian Agricultural Experiment Station, at the Bureau of Chemistry, U.S.D.A., for the Hawaiian Sugar Planters Association, associate professor, professor, and head of the department of agricultural chemistry at the University of Arizona, and State

chemist in charge of feed, fertilizer, and insecticide control. Prof. McGeorge is the author of over 100 technical papers. He is noted for his originality in research. Among his more important papers are those dealing with phala blight of sugar cane, base exchange, the use of concentrated fertilizers, and the control of the chlorosis of citrus. He is a collaborator for the Western Regional Laboratory of the U.S.D.A., and has taken an active part in helping direct its activities. Professor McGeorge is a member of Sigma Xi, Phi Kappa Phi, and Phi Lambda Upsilon. Notwithstanding the fact that he has long been located "way out there in the desert where it is often hard for a man to take a prominent part in any national organization", he has been prominent in committee work for the Society. He is a fine fellow personally and a credit to the Society.

THEODORE EUGENE ODLAND

THEODORE EUGENE ODLAND was born on a farm near Rutland, North Dakota, January 11, 1892. He took his undergraduate work at the University of Minnesota and remained there for an M.Sc. The Ph.D. degree was conferred on him by Cornell University in 1926. Dr. Odland's professional career began when he became instructor in agronomy at the Morris substation at Morris, Minnesota. Following this he was successively instructor in agronomy at the University of Minnesota, assistant and associate professor of agronomy of the University of West Virginia, and head of the department of agronomy at the Rhode Island Agricultural Experiment Station. In addition he has served in the capacity of secretary of the Minnesota Crop Improvement Association, in the U. S. Naval Air Service during World War I, and as Food and Agricultural Officer with Civil Affairs and Military Government during World War II, from which position he was honorably discharged with the rank of Colonel. He has been a member of the Society since 1920 and has been a frequent contributor to the JOURNAL. He served as first chairman of the New England Section of the Society. Among his more unique publications are those dealing with the effects of crops on those that follow, fertilizer studies with vegetable crops, lawn and golf-course grasses, and pasture research. He is a member of Sigma Xi, Alpha Zeta, Phi Kappa Phi, and Gamma Sigma Delta. Dr. Odland is a modest, unassuming man with an enviable record for service to his country and to the cause of agronomy.

WILBUR LOUIS POWERS



WILBUR LOUIS POWERS was born on a farm near Tiskilwa, Illinios, March 5, 1887. His undergraduate work was taken at the University of Illinois and the M.Sc. degree from New Mexico College. The Ph.D. degree was conferred on him by the University of California. Dr. Powers' professional career began with his appointment as assistant in soils at New Mexico. Following this he was successively assistant agronomist, professor of irrigation and drainage, and professor of soils at Oregon State College. In addition he has served in the capacity of consultant to the U. S. Bureau of Reclamation. Dr. Powers is the author of numerous publications on irrigation, drainage, minor elements in plant nutrition, and organic colloids in soils. One of his most unique contributions to soil-plant science was in relation to the sulfur content of Oregon soils and the need to supply this element as such or a calcium sulfate for the production of optimum yields of alfalfa and such other crops as have high sulfur requirements. Dr. Powers has played a highly important part in the development of the agriculture of the Northwest. He has been an active member of the Society for many years. His personal and intellectual qualifications entitle him to a high place among his colleagues in the field of agronomy.

CLAYTON ORD ROST

CLAYTON ORD ROST was born on a farm near Ord, Nebraska, November 24, 1885. His undergraduate work was taken at the University of Nebraska, where he also obtained the M.Sc. degree. The Ph.D. degree was conferred on him by the University of Minnesota in 1918. Dr. Rost's professional career began with his appointment as assistant agricultural chemist at the Nebraska Agricultural Experiment Station. Following this he became successively assistant professor, associate professor, and professor and chief of the department of soils at the University of Minnesota. He has made highly important contributions to the agriculture of his state. He has published a large number of bulletins and papers on soil phosphates, soil acidity, and soil genesis. His scientific work in relation to the chemistry of prairie and glacial soils has been especially noteworthy. Dr. Rost has long played a very

active part in the work of the American Society of Agronomy, having served on numerous committees. He is a member of Phi Beta Kappa, Sigma Xi, and Alpha Zeta. He brings a fine personality as well as a high degree of intellectual attainment to bear in his relationships with others.

GEORGE FREDERICK SPRAGUE

George Frederick Sprague was born on a farm near Crete, Nebraska, September 3, 1902. His undergraduate work was taken at the University of Nebraska where he also obtained an M.Sc. degree. The Ph.D. degree was conferred on him by Cornell University in 1930. Dr. Sprague's professional career began with his appointment as junior agronomist of the Bureau of Plant Industry of the U.S.D.A. Following this he became successively assistant agronomist, associate agronomist, agronomist, and senior agronomist. He was first located in Nebraska, and later in Virginia, Missouri, and Iowa. Dr. Sprague is the author of numerous papers on the genetics and breeding of corn. He has been specially interested in determining the causes of hybrid vigor and in the improvement of corn-breeding techniques. The corn hybrids he has helped to develop for the northern half of Iowa have made an exceptionally good showing and are rapidly replacing the earlier hybrids for that area. Dr. Sprague has long been an active member of the Society and has served on some of its most important committees. His record of attainment has been such as to place him among the top leaders in his field of endeavor.

SILVERE CYRIL VANDECAVEYE

Silvere Cyril Vandecaveye was born at Zonnebeke, Belgium, January 11, 1888, and became a naturalized citizen of the United States in 1919. He took his undergraduate work at Michigan State College and obtained his M.Sc. at Iowa State College, where the Ph.D. degree was conferred on him in 1923. Dr. Vandecaveye's professional career began with his appointment as bacteriologist at the Washington Agricultural Experiment Station. Following this he became professor of soils and soil biologist at Washington State College and Experiment Station. Dr. Vandecaveye's research interests have been in the field of plant nutri-

tion, soil microbiology, and soil fertility. He has published numerous papers, among the most notable of which have been those dealing with the problem of soil organic matter in relation to the agricultural practice in the Northwest. Dr. Vandecaveye is a member of Sigma Xi, Phi Kappa Phi, and Gamma Sigma Delta. He has been a regular attendant at the meetings of the Society for many years and has played a very active part as a member of its several committees. His scientific attainments are buttressed by a fine personality that makes him a welcome member in any group of his fellowmen.

CLYDE MELVIN WOODWORTH

CLYDE MELVIN WOODWORTH was born in Canton, Illinois, February 28, 1888. His bachelor's degree was obtained at the Oklahoma Agricultural and Mechanical College and his M.Sc. degree at the University of Wisconsin, where the Ph.D. degree was also conferred upon him in 1920. Dr. Woodworth's professional career began with his appointment as assistant in agronomy at South Dakota State College, after which he became successively assistant in the U.S.D.A., assistant and instructor in genetics at the University of Wisconsin, and assistant pathologist in the U.S.D.A. In 1920 he was appointed assistant professor of plant breeding at the University of Illinois from which he was later advanced to associate professor and then to professor and chief in plant genetics. His scientific activities are in the field of plant genetics with particular reference to soybeans, of which the Chief, Illini, and Viking are the 3 main varieties for which he has been responsible. His advice and counsel on soybean breeding are widely sought, not only in this country but abroad as well. Many foreign students come to Illinois to study under his direction. Dr. Woodworth has also been closely identified with the rapid development of hybrid corn in Illinois. He enjoys a high rating as a scientist on his own campus where he served as one of the first presidents of Gamma Sigma Delta, and, more recently, as president of Sigma Xi. Dr. Woodworth has been the author or coauthor of a large number of bulletins and journal articles. He has made highly important contributions to his field of science and has served the Society for many years. He is a quiet, unpretentious man with a fine record of accomplishment.

Minutes of the Thirty-Ninth Annual Meeting of the American Society of Agronomy

THE thirty-ninth annual meeting of the American Society of Agronomy was held at the Netherland Plaza Hotel in Cincinnati, Ohio, November 17 to 20, 1947. There were 924 members and guests registered in attendance.

The general meeting of the Society was held on Wednesday, November 19. Dr. A. G. Norman, Camp Detrick, Maryland, presented a paper on "Agronomic Uses of Plant Growth Regulators" and G. S. Robertson, Director of the Agricultural Division, F. A. O., discussed the "F. A. O. and the World Food Problems". Both papers were well received by the members present.

The annual dinner was held Wednesday evening at which time Dr. W. H. Pierre gave the Presidential Address on "The Phosphorus Cycle and Soil Fertility". Professor H. D. Hughes, Past President of the Society, presented certificates to the Fellows Elect as follows: H. H. Bennett, H. P. Cooper, W. T. McGeorge, W. L. Powers, C. O. Rost, S. C. Vandecaveye, T. H. Goodding, R. E. Karper, B. A. Madson, T. E. Odland, G. F. Sprague, C. M. Woodworth, and C. E. Marshall. Dr. G. H. Dungan, Chairman of the Committee on Student Sections, presented awards to the winners in the Essay Contest. These are announced in the report on the Student Sections.

There were a total of 46 divisional and sectional programs, conferences, and discussions at which 293 papers were presented. These were divided as follows: Crops Science Division, 93 papers; Soil Science Society of America, 121 papers; Agronomic Education, 16 papers; Applied Agronomy, 30 papers; and Joint Programs, 33 papers.

The newly elected officers of the Society are as follows: President, O. S. Aamodt; Vice President, Firman E. Bear; Chairman Crops Science Division, H. K. Wilson; Chairman Soils Division and President of the Soil Science Society of America, N. J. Volk.

The annual business meeting was held following the general meeting on Wednesday, at which time the reports of the officers and committees were presented. These reports are appended hereto.

G. G. POHLMAN, *Secretary*.

OFFICERS REPORTS

REPORT OF THE EDITOR

THE statistics pertaining to the 1947 volume of the JOURNAL are as follows:

Contributed papers published	105
Notes published	25
Book reviews	25
Approved papers awaiting publication	7
Papers under review	22
Number of papers rejected	13
Total to November 1, 1947	197

This compares with 165 articles of all kinds that passed through our hands in a similar period in 1946.

We are somewhat ahead of last year in number of papers on hand and thus are made up further into the next volume, at least tentatively, than is usual at this time. The JOURNAL is still in a position to offer fairly prompt publication, however, as compared with most scientific journals. The 1947 volume—Volume 39—will contain substantially the same number of pages as Volume 38.

Publication costs will undoubtedly continue to rise in 1948 as wage agreements come up for review at the beginning of the year for both printers and photo-engravers.

According to a survey made by the Printing Industry of America, Inc., wages and salaries paid to management and to workers account for nearly 45 per cent of the total cost of printing, indicating that printing is one of the highest wage cost industries in the country. Much the same thing might be said with respect to the photo-engraving industry. Paper and printing supplies, on the other hand, seem to have leveled off somewhat and there is no substantial increase antitipated in these items. Also, the quantity and the quality of paper stock are markedly better than a year ago, and I believe you will note a distinct improvement in the appearance of the JOURNAL in 1948 from the standpoint of paper.

Just how long the Society can continue to absorb rising costs of publication without increasing its membership fees and subscription rates is questionable. At present we are operating under a membership dues and subscription structure established in the early 1920's which is not a very realistic approach to 1947 and 1948 costs. Also, the present surcharge schedule for extra pages and for illustrations had its inception sometime along in the 1920's and is wholly out of step with present costs. Some of you who have published recently in the JOURNAL have been confronted with unexpectedly high surcharges, especially for illustrations, yet it goes without saying that any relief to contributors along these lines depends upon the ability of the Society to absorb more of the overhead.

We suggested last year that the time had come to give serious consideration to an increase in dues. We repeat the suggestion and also recommend a general overhauling of the surcharge structure in the light of present-day experience.

All that is said here regarding the JOURNAL applies with even greater force to the PROCEEDINGS of the Soil Science Society, for the burden is eased somewhat for the American Society of Agronomy by its larger membership and greater resources which tend to mask the seriousness of a situation which is even more apparent in the case of the PROCEEDINGS.

The advertising income in the JOURNAL reached a new all-time high during 1947 and seems to bid fair to carry over into 1948. Our expanding circulation and the eventual expansion of the Society's whole program under the plans that are now taking shape should make the publications of this Society an increasingly attractive medium for advertisers.

It is our opinion that, on the whole, the presentation of papers in the JOURNAL is well done and that the scholarly tone of its pages has, in general, attained a noticeably higher plane with the passing years. Much of this is due to the efforts of the contributors themselves; some to the extreme care with which papers are reviewed by the Editorial Board and those whom the Board calls upon to assist it in this important task.

Correspondence during the past year both with respect to the JOURNAL and the PROCEEDINGS has convinced us that there is a real need for a revision of existing material that might aid contributors to the technical publications of the American Society of Agronomy and the Soil Science Society. There are at least three places in the JOURNAL and one in the PROCEEDINGS of past years where attempts have been made to provide such aids. It might be helpful to review these so-called "guides" and consolidate their best features in a single place for the information of those who wish to use the technical publications of the two societies. We have therefore undertaken to prepare such a revision and are recommending its publication to the Executive Committee of the two societies.

We wish to take this opportunity to express our thanks to the members of the Editorial Board, to Doctor Pohlman and his staff, to those of you who have supplied us from time to time with news items for the JOURNAL, and especially to all who have used the JOURNAL this past year for their patience and cooperation.

Respectfully submitted,

J. D. LUCKETT, *Editor.*

REPORT OF THE SECRETARY

IT IS indeed a pleasure to report the progress of our Society this year. Both memberships and subscriptions have continued to increase as shown by the following summary.

MEMBERS

Members, October 31, 1946		1,499
New members	299	
Dropped und unpaid	125	
Net increase		174
Membership, October 31, 1947		1,673

SUBSCRIBERS

Subscriptions, October 31, 1946		799
New subscriptions	321	
Dropped	247	
Net increase		74
Subscriptions, October 31, 1947		873

The tabulation of paid-up members and subscribers by states and countries is as follows:

	Members	Subscribers
Alabama	20	4
Arizona	21	2
Arkansas	9	5
California	87	43
Colorado	25	3
Connecticut	19	5
Delaware	3	2
District of Columbia	47	56
Florida	32	4
Georgia	53	9
Idaho	18	5
Illinois	83	19
Indiana	48	4
Iowa	76	7
Kansas	39	3
Kentucky	16	4
Louisana	32	16
Maine	7	1
Maryland	86	6
Massachusetts	14	3
Michigan	32	5
Minnesota	51	10
Mississippi	26	4
Missouri	22	10
Montana	11	6
Nebraska	50	6
Nevada	5	1
New Hampshire	4	1
New Jersey	25	5
New Mexico	12	5
New York	61	46
North Carolina	37	3
North Dakota	22	1
Ohio	56	10
Oklahoma	16	7
Oregon	28	8
Pennsylvania	47	11
Rhode Island	8	1
South Carolina	24	4
South Dakota	12	1
Tennessee	27	7
Texas	83	21
Utah	22	9
Vermont	2	1
Virginia	31	4
Washington	30	8
West Virginia	9	1
Wisconsin	48	11
Wyoming	6	2
Africa	3	24
Alaska		3
Argentina	6	29
Australia		37
Belgium		3
Brazil	9	20
British Guiana		1
British West Indies	1	3
Canada	31	45
Ceylon		2
Chile	3	2
China	5	26
Columbia	7	9
Costa Rica	1	
Cuba	4	4
Czechoslovakia	1	
Denmark	2	1
Dominican Republic	1	
Egypt		4
England		14
Fiji		1
Finland		5

	Members	Subscribers
France		11
Germany		3
Greece	1	2
Guatemala	1	1
Haiti	1	
Hawaii	8	12
Holland	1	7
Honduras	2	1
Iceland		1
India	4	26
Indo China		4
Iraq		1
Ireland		8
Italy	1	9
Malaya		3
Mauritius		1
Mexico	16	4
Netherland East Indies		1
Newfoundland		1
New Zealand		8
Norway		3
Palestine	2	3
Paraguay		1
Peru	4	4
Philippine Islads	1	1
Poland		2
Portugal		6
Puerto Rico	6	4
Salvador	1	
Scotland	2	2
Spain		4
Sweden	1	3
Switzerland	1	1
Syria	1	1
Turkey		2
Uruguay	1	3
U. S. S. R.		82
Venezuela	2	2
Wales		2
Total	1,673	873

The increase in members is particularly gratifying. The number of members increased in 36 states, with large increases in Georgia and Washington. The small decrease noted in a few of the states is undoubtedly due to transfer rather than to decreased interest in the Society. There has been little change in the number of foreign members.

The subscription list has increased both in this country and abroad. The large apparent increase in subscriptions to Russia is the result of our now sending these directly to the Soviet, rather than mailing them to New York for reshipment.

Up to the present time we have had representatives only on a state basis. These men have been primarily responsible for the maintenance and increase in our membership and subscription list. I believe we have reached the point where we might expand further and ask some of our foreign members to work with us in the expansion of the Society. We know that membership in the American Society of Agronomy is an honored privilege which we enjoy. Let's share this privilege with others.

Respectfully submitted,
G. G. POHLMAN, *Secretary*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year ending October 31, 947.

RECEIPTS

American Society of Agronomy	$19,488.75
American Society of Agronomy Development and Endowment Fund	7,655.51
Soil Science Society of America	7,921.23
Marbut Memorial Fund	75.10
Endowment Fund I. S. S. S	25.00
Total receipts	$35,165.59
Balance in bank, October 31, 1946	8,317.02
Total	$43,482.61

DISBURSEMENTS

American Society of Agronomy	$20,172.54
American Society of Agronomy Development and Endowment Fund	13.78
Soil Science Society of America	8,928.02
Marbut Memorial Fund	3.32
Endowment Fund I. S. S. S	28.57
I. S. S. S	5.00
Total disbursements	$29,151.23

Balance in bank, October 31, 1947	$14,331.38
Balance in savings bonds	2,760.00
Total	$17,091.38
Less checks outstanding	406.33
Total assets, October 31, 1947	$16,685.05

These assets are divided as follows:

	Cash in Bank	*Savings Bonds*	*Total*
American Society of Agronomy	$4,439.24		$4,439.24
A. S. A. Development and Endowment Fund	7,641.73		7,641.73
Soil Science Society of America	180.98		180.98
Marbut Memorial Fund	628.16		628.16
International Society of Soil Science	1,147.48		1,147.48
I. S. S. S. Endowment Fund	293.79	$2,760.00	3,053.79
Total	$14,331.38	$2,760.00	$17,091.38

The receipts and disbursements of the American Society of Agronomy were as follows:

RECEIPTS

Convention receipts	$ 1,607.50
Miscellaneous	118.88
Advertising	2,139.13
Reprints	2,628.84
Journals sold	579.41
Subscriptions, 1946	138.00
Subscriptions, 1947	3,815.50
Subscriptions, 1948	462.00
Dues, 1946	143.52
Dues, 1947	7,646.37
Dues, 1948	105.25
Membership only	75.00
Student members	6.00
Index	23.35
Total receipts	$19,488.75
Balance in cash, October 31, 1946	5,123.03
Total	$24,611.78

DISBURSEMENTS

Printing the JOURNAL	$13,185.68
Salary of Editor	582.00
Postage	311.58
Miscellaneous printing	195.16
Mailing clerk and stenographer	1,680.27
Refunds, checks returned	131.11
Expenses for annual meeting	2,008.06
Expanded program	1,071.82
Miscellaneous	1,006.86
Total disbursements	$20,172.54
Balance in bank, October 31, 1947	$ 4,439.24

DEVELOPMENT AND ENDOWMENT FUND

RECEIPTS

Member contributions	$ 7,555.51
Contributions from industry	100.00
Total	$7,655.51

DISBURSEMENTS

Miscellaneous bank charges	$ 13.78
Balance in bank, October 13, 1947	$ 7,641.73

Our financial condition is still sound. Our balance is slightly less than last year, due in part to increased costs and in part to the amount of financing allotted to the enlarged program. Receipts were $1,985.68 above those for 1946. The largest increases were for advertising, subscriptions, and dues. The largest increase in disbursement was for printing the JOURNAL. Costs may continue to increase so to maintain our financial condition we must keep our Society growing.

Respectfully submitted,
G. G. POHLMAN, *Treasurer*

REPORT OF THE AUDITORS

THE books of the Treasurer of the American Society of Agronomy and of the Soil Science Society of America have been examined by the auditing committee appointed by President Pierre. The books were found to be in good order.

G. M. BROWNING
H. R. ALBRECHT, *Chairman*

COMMITTEE REPORTS

PASTURE IMPROVEMENT

AT the annual meeting of the Society held at Omaha, Nebraska, November 19 to 22 in 1946, the Society's Pasture Committee outlined a total of 20 items which it might sponsor or promote. Foremost in the opinion of the committee at that time was a suggestion that a pasture handbook covering the United States and Canada be prepared as soon as possible. This handbook was to have been prepared by various members of the committee and other workers in the United States and Canada in a position to make significant contributions. Some time after the meeting it was learned that the 1948 U. S. Department of Agriculture Yearbook is to be entitled "Grassland Agriculture." In view of this it was the opinion of the committee that further consideration of this item be deferred until after the publication of the 1948 edition of the Yearbook.

Among the remaining 19 items, the committee felt that the three listed below should receive detailed study and investigation as soon as possible.

1. Preparation of a complete directory to include the names of all individuals in the United States and Canada working in the field of pasture improvement together with general summaries covering the nature of their work.

2. An investigation into the possibility of holding joint symposia with other societies such as the A.S.A.P. and A.D.S.A.

3. Revision of the report of the Joint Committee on Pasture Techniques.

A comprehensive questionnaire covering item number one has been prepared and sent to all pasture workers at the State Agricultural Experiment Stations and the federal services (Bureau of Plant Industry, Bureau of Animal Industry, Soil Conservation Service and Forest Service) in the United States and Canada. As soon as the questionnaires have been completed and returned they will be summarized and made available to all workers interested in pasture improvement in the United States and Canada.

R. E. BLASER
B. A. BROWN
E. M. BROWN
M. HEATH
M. A. HEIN
R. L. LOVVORN
R. H. LUSH
G. O. MOTT
V. G. SPRAGUE
T. M. STEVENSON
H. L. AHLGREN, *Chairman*

NEW PUBLICATION

THE Committee on the New Publication developed the following recommendations by correspondence, frequent meetings of four members of the committee, and consultation with Doctors Pierre, Aamodt, and Truog:

1. The first essential step in the development of the proposed publication is the selection of an Executive Secretary and/or an Editor. Financial considerations lead us to recommend the employment of only one man qualified to start and develop the new publication. In considering candidates, we have kept in mind the possibility of this man becoming Executive Secretary if he can secure an assistant to handle editorial work at a later date. On the other hand, the man employed might remain as Editor and the Society employ a second man as Executive Secretary.

Two candidates for the position have been recommended by this committee to the Executive Committee for consideration for this position. The committee has not had an opportunity to interview several individuals who have been recommended, therefore it is suggested that the Executive Committee may wish to consider other candidates.

2. "Agronomic Progress" should tentatively be adopted as the name of the new publication. Further discussion of a name should await the selection of the Executive Secretary and/or an editor and his recommendations be considered.

3. Agronomic Progress should be a monthly publication of at least 32 pages and of a size and format similar to the preview issue.

4. A subscription price of $2.00 to $3.00 per year for Agronomic Progress is suggested. Final determination of subscription rates should await better data on costs, advertising income, and circulation. The Society may also wish to review subscription prices of its present publications.

5. Permanent headquarters for the Society should be established in a small to moderate sized city, and preferably in the same city as the publisher. A location in the central part of the country is generally preferred.

6. Estimates of income and costs indicate the Society should have a reserve of approximately $25,000 before initiating the new publication. Such a reserve would assure operation for two years. The project should then be self-supporting.

7. The Society should appoint an editorial board for Agronomic Progress. It would be the duty of this board to assist in the development of Agronomic Progress and advise the Executive Committee and the Editor on all matters of policy.

J. E. ADAMS	F. E. BEAR
F. W. PARKER	C. F. SIMMONS
GROVER F. BROWN	J. D. LUCKETT
J. R. TAYLOR	H. D. HUGHES
JOHN H. PARKER	K. S. QUISENBERRY, *Chairman*
PAUL H. STEWART	

ORGANIZATION OF REGIONAL BRANCHES OF THE SOCIETY

IN order to promote the best interests of the field of agronomy and those scientists engaged in the agronomic field, it is recommended that a Regional Branch of the American Society of Agronomy be organized in the Northeastern, Mid-Western, Southern, and Western Regions of the United States and that these branches affiliate themselves with the American Society of Agronomy, if they have not already organized or affiliated themselves with the National Society. At the suggestion of Canadian agronomist, it is not recommended that separate regional branches be organized in Canada at the present time but that the regional branches in the United States invite society members in Canada to affiliate themselves with that regional branch which is most conveniently located.

In order to define the relationship between the regional branches and the National Society, the committee makes the following specific recommendations:

1. That the regional branches be formally organized with the properly elected officers in order to perform those functions set out in the new constitution adopted by the American Society of Agronomy, but that all matters pertaining to the organization thereof, such as membership requirements, dues, kind and number of meetings, be left to the discretion of the regional branch.

2. That members of the regional branch, not otherwise affiliated with the National Society, be by virtue of such regional membership, associate members of the American Society of Agronomy with the privileges provided by the constitution and by-laws of the National Society.

3. That official publications of the National Society give consideration to the publication of acceptable papers previously rendered at regional branch meetings and recommended by the regional branch for publication or for the national meeting program.

4. That the meeting of the national organization be rotated within the four regions, as far as possible, on the basis of membership in order to allow all regional members an opportunity to attend the National Society's meeting.

Rotation of the national meeting should probably be made on the basis of the number of members of the Society within the several regions. If fifty per cent of the national membership were located in one region, perhaps this region should hold fifty per cent of the number of meetings. Rotating the national meetings in the various regions would allow all regional members to attend national meetings occasionally. This would probably allow a closer relationship between the regional branch and the National Society.

5. That as many local matters as possible be handled by regional branches in order to lessen the load at the national meeting.

In the expanded society program more and more problems will arise and unless many of them are handled by the various regional branches, the national meeting may evolve into a long business session. The regional branch meetings could help serve as a clearing house for matters to be passed upon by the National Society.

6. That the National Society, when so requested by the regional branch, assist in arranging for outstanding speakers at regional branch meetings.

In some cases speakers may be out of place at the regional branch meetings, but in many cases it may be desirable to have outstanding national or international speakers. The National Society might arrange and pay for a part or all of the expenses for such speakers.

7. That state branches be encouraged to organize and to affiliate themselves with the regional branch, but that no attempt be made to organize branches in all states at the present time.

Some states already have state organizations which consider themselves affiliated with the American Society of Agronomy. It is hoped that these states will continue to maintain interest in state branches; however, it does not seem feasible at the present time to organize a state branch in each state. After the regional branches are organized and the membership of the Society is enlarged, it may be desirable that state branches be organized in each state.

G. K. Middleton — Harold Myers
S. S. Obenshain — S. P. Swenson
T. E. Odland — Omer Kelley
P. R. Miller — J. B. Harrington
D. R. Dodd — Alfred Leahy

Russell Coleman, *Chairman*

STUDENT SECTIONS

During the past year 17 student sections, having 592 members, have been active. They are located in the following institutions: Brigham Young University, Clemson Agricultural College, Colorado State College of Agriculture, University of Georgia, University of Illinois, Iowa State College, Kansas State College, Louisiana State University, Michigan Agricultural College, Mississippi State College, University of Nebraska, University of North Carolina, Oklahoma A. and M. College, Purdue University, South Dakota State College, A. and M. College of Texas, and the Virginia Polytechnic Institute.

In order to start the National Conference of Student Sections, officers were appointed by the Committee on Student Sections as follows: President—D. B. Rosenkrans, Jr. of South Carolina; Vice-president—Robert Brown of Iowa; Secretary—Glendon M. Smith of Indiana; and Treasurer—George W. Kunze of Texas. The function of these officers is to call a meeting of representatives of the different student sections for the purpose of electing officers for the coming year and to transact any business which may properly be brought before the meeting.

[Room 204 Navy Pier Building, Chicago Undergraduate Division, University of Illinois has been reserved for 9 A.M. on Nov. 29 for this meeting.]

The essay contest for 1947 has been completed. The subject was "Effect of Soil Fertility on the Quality of the Wheat Crop." Five essays from that many institutions were entered. These were rated by R. J. Muckenhirn and E. J. Graul of Wisconsin; A. W. Crain, L. Whiteley, and E. S. McFadden of Texas; and G. C. Klingman and G. K. Middleton of North Carolina. Winners of the contest were Charles M. Smith of Iowa, first place; Jack V. Baird of Nebraska, second place; Dale W. Bohmont of Wyoming, third place; and Carl Ryther of South Dakota and Dwight M. Wilson of Illinois tied for fourth place.

The $100.00, contributed jointly by Dr. M. A. McCall and The Northwestern Miller, to be awarded to winners has been distributed as follows: First place $30, second place $25, third place $20, and the two who tied for the fourth place $12.50 each.

Medals in the form of a key bearing the inscription, "Agronomy Essay Contest" are awarded by the Society to winners of the first three places. First is gold, second is silver and the third is bronze.

Abstracts of the first three essays are appended to this report in order of their rating.

The subject of the essay for the 1948 contest is "Soil Factors Affecting the Nutritive Value of a Forage Crop." The student may choose a forage crop in which he is especially interested. Rules of the contest will follow the general lines of the 1947 essay contest.

W. O. COLLINS
R. L. CUSHING
G. C. KLINGMAN
R. J. MUCKENHIRN
R. C. POTTS
ERIC WINTERS
G. H. DUNGAN, *Chairman*

EFFECT OF SOIL FERTILITY ON THE QUALITY OF THE WHEAT CROP

There are many factors controlling quality wheat production. Of these, most investigators agree that environment (climate, rainfall, temperature, etc.) has probably the greatest influence, soil fertility ranks second in importance, with the variety of wheat grown having the least effect.

Although it is very evident that environment and variety are of utmost importance, the main considerations in this paper relate to soil fertility.

The term "quality" is very difficult to define. In general it concerns test weight per bushel, per cent crude protein, suitability for intended use, and strength of gluten. Since there is a high correlation between gluten and protein content, it has become customary to use the per cent of protein as a measure of quality rather than per cent gluten for it is more accurate and is easier to determine.

Most investigators have used for measures of quality only test weight and protein content. Too few of the tests have been carried to completion by conducting actual baking tests.

There are many trends of thought particularly about the proper determination of and the causes of variation in quality. It is felt that the following conclusions can be drawn if protein content and test weight per bushel are accepted as the main criteria for judging quality:

1. The effectiveness of nitrogenous fertilizers in increasing protein content increases as the time of application approaches heading time.
2. Phosphate decreases the protein content but increases the test weight per bushel.
3. Potash fertilizer has the same general effect as phosphate but to a lesser degree.
4. A negative correlation usually exists between test weight and percentage protein. This is probably due to the fact that plump kernels are usually comparatively low in protein and shriveled ones high.
5. Nitrogen application at heading time prevents "yellow berry".
6. With an increase in nitrogen content of the grain, a similar increase in sulfur occurs, indicating that the nirtogen is being added as true protein.
7. When nitrogen is applied at heading time, particularly in periods of adverse weather conditions, the resulting wheat is superior in all characteristics.
8. Barnyard manure often produces the highest test weight.

9. Fertilization in early spring has no significant effect on blending strength, as indicated by loaf volume.

10. A limited potassium supply results in the following: an increase in the dry matter, calcium and magnesium, and a decrease in nitrogen; retarded growth with a reduced total amount of individual nutrients absorbed; an increase in the proportion of grain to total yield; an adverse effect on the quality of the grain as determined by baking and gluten tests. The composition of the grain is not altered as much as the rest of the plant.

A linear relationship exists between loaf volume and protein content, where gas production is not a limiting factor and when flours of similar protein character are tested.

Wheat is usually bought, sold and blended on the protein test basis, but this is a test of quantity of protein, not quality. Therefore, as the wheat varieties vary in quality the protein determination loses value.

Results of tests show that soil fertility definitely influences quality in wheat. Soil fertility is rapidly declining, particularly in the humid regions, indicating a probability of a wheat of lower quality for the future. However, by the addition of the proper amounts of the right fertilizers to the soil, wheat of satisfactory quality can be produced. Also, since most components of quality are hereditary, they can be improved to some extent by the breeder.—CHARLES M. SMITH, *Iowa State College, Ames, Iowa.*

HOW NITROGEN AND PHOSPHORUS AFFECT THE PROTEIN CONTENT AND YIELD OF WHEAT

As a result of a system of farming in the wheat growing areas in which the soil has been depleted of its more essential elements, the protein content of wheat has been reduced and the yields have fallen off. Economic conditions have caused people to "mine" their soil in a manner to obtain the largest wheat yields over a long period of time with little addition to the soil of the necessary elements. Nitrogen and phosphorus deficiencies were the first to appear resulting in much research and experimental work to determine proper fertilizers to use for wheat, the proper amounts to apply, and the reactions of wheat to the various fertility treatments.

In general, there are three sources of nitrogen and phosphorus which may be used to return these depleted nutrients to the soil. Barnyard manure and green manure crops are the farm supplied sources. These elements of fertility are the cheapest regardless of the system of farming, but only through proper handling are they effective. Commercially prepared fertilizers, which are concentrated in form, are more expensive per ton. These fertilizers, whether straight or mixed, are used to supplement in the fertility program if there are insufficient supplies of other available sources of nitrogen and phosphorus.

Nitrate deficiencies in wheat are most likely to occur in the spring of a cool wet season. The deficiency is reflected in the plant by stunted growth and a pale, yellow-green color.

Phosphorus deficiencies occur in the soil after all parent material containing phosphorus has disappeared. A lack of phosphorus usually causes in wheat poor root growth, late maturity, shrunken seeds, and reduced disease resistance. Phosphorus is slowly soluble and becomes available only through bacterial action upon it.

In all studies conducted over wheat raising areas, the majority of the tests revealed that nitrogen applied to wheat gave a profitable increase in yields and a higher protein content in the grain. The best results were obtained when the application of nitrogen was applied in the spring at the time the wheat was 8 to 10 inches tall. Larger increases in yield were obtained using the same amounts when applied to dark, heavy-textured soils rather than to the lighter-textured soils. In addition, net increases in yields were higher when moisture conditions were favorable rather than somewhat limited.

In the rather recent tests with phosphate fertilizers, substantial increases in yields have been obtained on phosphorus deficient areas. It is generally concluded in all the experimental plots that a mixed fertilizer containing phosphorus gave higher yields than phosphate fertilizers used alone. More phosphorus-supplying power is released in the mixed fertilizer. Phosphate fertilizers are applied once during a period of 8 to 12 years as contrasted with the annually applied nitrogen.

In addition to increased yields, phosphorus applied to deficient areas caused the wheat to mature earlier and, in turn, the wheat ripened before injurious pests, disease, and heat damage occurred.

A close relationship exists between nirtogen and phosphorus in its use. There are depressing effects if too much of each is used or if too much of both are used. A satisfactory balance between the elements is highly desirable for largest profits. Local areas and state agricultural stations have adapted the correct combinations of fertilizer to be used for largest yields and the maximum protein content of wheat. —JACK V. BAIRD, *University of Nebraska, Lincoln, Neb.*

THE EFFECT OF SOIL FERTILITY UPON THE QUALITY OF THE WHEAT CROP

It has long been an established fact that the composition of wheat varies from year to year and from locality to locality. The reason or reasons for this variation have been a problem which has challenged enterprising agronomists the world over and has yet been only partially answered.

Wheat grain is composed chiefly of protein and starch; because the chemical composition of the wheat determines its eventual use, the word "quality" generally refers to the composition of the kernel.

An adequate supply of soil nutrients is necessary for normal plant growth. It follows that by increasing the availability of the elements which influence protein synthesis the quality of the wheat produced may be affected.

There are many elements necessary for normal plant growth, some being of more importance in the production of high quality wheat than others. Striking results have been obtained by application of commercial fertilizers containing these elements.

Application of nitrogen fertilizer resulted in the production of a wheat which was high in protein and which milled into bread flour of choice quality. It is essential that an ample supply of nitrogen be present in the soil during the heading period since it is at this period of growth that the plant uses the most nitrogen.

A correct balance between phosphorus and other nutrients will greatly increase the quality of the wheat kernel by insuring plumpness of the grain. When present in too large amounts, phosphorus will decrease the protein content of the kernel.

Because potassium and calcium indirectly effect the formation of protein in the wheat crop, it is desirable to see that adequate amounts are provided.

Sulphur, magnesium and iron influence the plant growth and the composition of the plant. However, they are usually applied only when deficiency symptoms occur.

By maintaining soil fertility through the practice of crop rotation and the application of barnyard manure, the quality as well as the quantity of the wheat crop is generally increased substantially.

The effect of soil fertility upon the plant has been extensively studied, but there is still much more about the relationship between fertility and the plant which is not known and which agronomists need and are eager to know. Fertilizer influences the quality of wheat and will continue to be a prime factor in the production of the world's most important food crop.—DALE W. BOHMONT, *University of Wyoming, Laramie, Wyo.*

AGRONOMIC EDUCATION

THE committee on education in cooperation with the committee on extension participation organized one joint session on resident and extension teaching. In addition one session was devoted to resident teaching problems.

An expression of opinion of those in attendance at the meetings indicated that the group was interested in organizing a special division on resident teaching-extension with two distinct sections. It was recommended that no attempt be made to organize the division at this time but that the trial period be continued another year under the direction of a committee.

Respectfully submitted

L. M. TURK	W. C. LIBBY
D. W. THORNE	K. H. KLAGES
O. T. COLEMAN	G. C. KLINGMAN
G. H. DUNGAN	H. E. MYERS, *Chairman*

SOIL TILTH

THE Soil Tilth Committee reported last year that a manuscript to be offered as a monograph was being prepared on the subject, "The Influence of Soil Physical Conditions on Plant Growth." We now have the manuscript in first draft stage. The committee held a two-day meeting on November 15 and 16 to consider the first draft and suggest modifications to the several authors for its improvement. We will now make the needed revisions. Our time schedule calls for a second revision and for the final draft of the manuscript to be completed by June 1, 1948, at which time we will offer the manuscript to the Committee on Monographs for consideration as a monograph of the Society.

For the American Society of Agronomy	For the American Society of Agricultural Engineers
J. F. LUTZ	I. F. REED
E. N. FERGUS	A. P. YERKES
T. M. MCCALLA	M. L. NICHOLS
M. B. RUSSELL	R. M. MERRILL
B. T. SHAW, *Chairman*	F. A. KUMMER, *Chairman*

DEVELOPMENT AND ENDOWMENT FUND

EARLY last spring, President W. H. Pierre asked me to organize a campaign to solicit subscriptions for the establishment of a Development and Endowment fund needed to finance the Society's expanded program which had been approved by vote of the members. Accordingly, to carry out this campaign, a national committee and a local committee in each state and Hawaii were organized. The names of those who kindly agreed to serve on the National Committee and as Chairmen of the local committees are given at the end of this report.

It had been estimated that a minimum fund of $25,000 would be needed to assure permanent success of the proposed expanded program of the Society. To demonstrate first of all that the membership of the Society is wholeheartedly backing this venture, it was decided to canvass the members prior to soliciting aid from industry. It is indeed gratifying to report that to date subscriptions from members now total slightly more than the goal of $10,000 which had been set. Additional subscriptions from members are still being received.

As soon as success of the membership campaign was assured, solicitation of industry, whose activities are connected quite closely with soil management and crop production, was begun. Here also it is gratifying to report that industry is responding generously, and there now exists little if any question but what a grand total of $25,000 will be subscribed by the members and industry.

Besides obtaining the needed funds, the Society is gaining other benefits from the campaign: First, the membership is becoming better acquainted with the important role which the Society can and should play in the welfare of its members, as well as the all important matter of crop production and soil conservation; and second, the Society is making its activities known to many in industry connected with crop production.

To all those who have supported this campaign with their time or money or both, I wish in behalf of the Society to give sincere thanks.

Respectfully submitted,
EMIL TRUOG, *General Chairman*

MEMBERS OF NATIONAL COMMITTEE

W. A. Albrecht
G. B. Bodman
Richard Bradfield
R. H. Bray
H. E. Brewbaker
J. A. Chucka
W. O. Collins
R. W. Cummings
H. L. Dunton
F. L. Duley
H. L. Garrard
E. A. Hollowell
C. D. Hoover
G. G. Pohlman
G. D. Scarseth
H. B. Siems
F. B. Smith
J. R. Taylor
S. C. Vandecaveye
C. J. Willard

CHAIRMEN OF LOCAL COMMITTEES

Alabama, L. E. Ensminger
Arizona, W. T. McGeorge
Arkansas, R. P. Bartholomew
California, G. B. Bodman
Colorado, D. W. Robertson
Connecticut, B. A. Brown
Delaware, C. E. Phillips
Florida, H. C. Harris
Georgia, W. O. Collins
Hawaii, G. D. Sherman
Idaho, K. H. Klages
Illinois, R. H. Bray
Indiana, H. R. Albrecht and B. R. Bertramson
Iowa, H. D. Hughes
Kansas, A. L. Clapp
Kentucky, E. N. Fergus
Louisiana, M. B. Sturgis
Maine, W. C. Libby
Maryland and D. C., F. W. Parker
Massachusetts, R. W. Donaldson
Michigan, C. E. Millar
Minnesota, C. O. Rost
Mississippi, C. D. Hoover
Missouri, W. A. Albrecht
Montana, A. H. Post
Nebraska, F. D. Keim
Nevada, L. E. Dunn
New Hampshire, F. S. Prince
New Jersey, F. E. Bear
New Mexico, Glen Staten
New York, Richard Bradfield
North Carolina, R. W. Cummings
North Dakota, L. A. Jensen
Ohio, C. J. Willard and R. E. Yoder
Oklahoma, H. J. Harper
Oregon, W. L. Powers
Pennsylvania, F. G. Merkle
Rhode Island, R. S. Bell
South Carolina, H. P. Cooper
South Dakota, L. O. Fine
Tennessee, W. H. MacIntire
Texas, J. E. Adams
Utah, H. B. Peterson
Vermont, A. R. Midgley
Virginia, H. L. Dunton
Washington, S. C. Vandecaveye
West Virginia, E. H. Tyner
Wisconsin, Emil Truog
Wyoming, T. J. Dunnewald

AGRONOMIC APPLICATIONS

AT THE request of President Pierre, following a favorable mail vote to enlarge the American Society of Agronomy, a committee was appointed to develop a program for the proposed new division on applied agronomy.

With this committees' assistance a program was presented consisting of five sections, as follows:

Seed Production.....................C. S. Garrison, *Chairman*
Fertilizer.........................R. W. Cummings, *Chairman*
Turf Management.....................Fred V. Grau, *Chairman*
Soil Conservation...................H. H. Gardner, *Chairman*
Pasture Section.....................H. L. Ahlgren *Chairman*

These programs were developed, stressing the practical application of research findings as bearing on the particular problems being discussed in each section.

Naturally, it was late when final returns from the voting was obtained to create a new division, so it was difficult to develop a more valuable and satisfactory program. It is expected that with this year's experience, many of these "growing pain" problems will be solved.

The Executive Committee has asked the members of the Committee on the Applied Division to carry over for both years while the Division is in the trial status.

VERNON A. YOUNG
HORACE J. HARPER
H. H. TUCKER
A. L. HAFENRICHTER
C. S. GARRISON
E. F. FROLIK
J. C. LOWERY
H. B. CHENEY
W. A. ALBRECHT
G. N. HOFFER
R. W. CUMMINGS
FRED V. GRAU
GROVER F. BROWN, *Chairman*

EXTENSION PARTICIPATION

WE WISH to report that extension agronomists increasingly are participating in the program of the Society. They are interested for two reasons, first, to keep up with new research developments, and second, to discuss problems of extension education both as to subject matter and methods.

We feel extension agronomists will fit into the Society as a part of one of the divisions. We suggest that this can probably best be accomplished by the organization of an Extension Section in a new Division of Agronomic Education. In addition, extension agronomists will participate actively in the applied agronomy programs.

This year the extension program consisted of a half day extension program, a breakfast, and a joint program with resident teachers. Attendance and interest was good. Extension agronomists also presented papers in other sections, particularly those in applied agronomy.

CLYDE LINSLEY	P. T. COLEMAN
R. H. TUCKER	C. S. GARRISON
J. C. LOWERY	C. P. WAYNE
P. M. BURSON	O. S. FISHER
	H. B. CHENEY, *Chairman*

MONOGRAPHS

THE American Society of Agronomy shall sponsor the publication of Monographs which deal competently and authoritatively with topics in the general professional field of agronomy.

The purpose of the Monographs is primarily to make available to students, research workers, and colleagues in other branches critical comprehensive reviews and connected reports on the state of our knowledge in the particular fields in which the authors are recognized leaders. Monographs should aim at bridging both in treatment and time the gulf between the technical journal paper and the text book. The volume of research publication today is such that to obtain a creditable perspective over even a limited field is a difficult matter. The Monographs would constitute a service to the profession and further the objectives of the Society.

The sponsorship of such Monographs by the Society does not necessarily involve direct publication by the Society or the assumption of financial risks; equally the Monographs should not be considered as a potential source of income.

Early publication of Monographs should be authorized. Publication can be effected by arrangement with Chronica Botanica whereby all expenses, including adequate advertising, are borne by that publishing house, and royalties are received by the author. The Editor, Dr. Frans Verdoorn, has indicated that he will accept a limited number of manuscripts recommended by the Society. Members would receive a substantial discount on pre-publication orders.

When the permanent secretariat of the Society, with full time Editor, has been established the Society might consider assuming the details and responsibilities of direct publication, or might continue to publish through Chronica Botanica with the Editor of the Society handling the editorial phases.

If the Society sponsors a Monograph and sets its cachet upon it by so doing, some machinery of review of the completed manuscript would be wise. Sponsorship does not imply indorsement, but it does guarantee that the treatment is authoritative and judicial.

The Committee has given consideration to the objectives and scope of a review publication, Advances in Agronomy, proposed by Academic Press, Inc., and has had particularly in mind competition with the Monographs, by duplication of material or efforts. It is not believed that the preparation of the Advances would hinder the production of Monographs. It would be desirable, however, that there should be some editorial cooperation so that the future plans of each are known to the other.

The Society can enter into an agreement with Academic Press, Inc., whereby an annual volume of reviews of progress in selected fields of agronomy entitled Advances in Agronomy can be issued under the sponsorship of the Society with an Editor nominated by the President of the Society and an Advisory Board in part constituted of members of the Monographs Committee. All financial responsibility would be assumed by the Academic Press, Inc. Members of the Society would receive a discount on the general publication price.

If the recommendations with respect to sponsorship of Monographs and Advances are approved, the Monographs Committee of the Society should be reconstituted as a Committee having primarily editorial functions with respect to

procurement, review, and editing of manuscripts to be published as Monographs by Chronica Botanica, and secondarily, responsibility for advising the Editor of the Advances as to topics deserving of review treatment, and authors from whom manuscripts might be solicited. To accomplish this objective it would be desirable that the personnel of the Committee should have some continuity in office which might be accomplished by replacing no more than one member each year in the field of crops and soil science.

R. BRADFIELD
E. A. HOLLOWELL
H. JENNY
H. H. LAUDE
N. P. NEAL
L. A. RICHARDS
A. G. NORMAN, *Chairman*

RESOLUTIONS

IT IS with profound regret that we take special notice at this time of the passing of eight of our colleagues since we last met in annual conclave. The list includes two Charter Members of the Society—Louie Henrie Smith and Charles Burgess Williams who was also President of the Society in 1926. The others are Andrew Boss, Clarence Dorman, Paul B. Dunkle, B. M. King, William Wylie Mackie, and William H. Ross.

Each in his own way made a notable contribution to the advancement of agronomy and to the success of this Society. In their passing many of us feel a deep sense of personal loss and all of us take pride in enshrining their names on the roll of those eminent agronomists who have passed on before. Brief biographical sketches are attached as a part of these memorials.

Respectfully submitted:

H. M. TYSDAL
K. E. BEESON
F. B. SMITH
J. D. LUCKETT, *ex-officio*
H. E. MYERS, *Chairman*

ANDREW BOSS

ANDREW BOSS, Professor Emeritus of Agricultural Economics and Farm Management, of the University of Minnesota, died on January 13, 1947. He was born on a farm near Lake City, Minnesota, June 3, 1867. Professor Boss was a graduate of the School of Agriculture, University of Minnesota, in 1891 and received honorary degrees of D.Sc. from Kansas State College in 1927 and from the University of Minnesota in 1945. Through the years he held many academic and administrative positions in the Department of Agriculture of the University of Minnesota including Farm Foreman, Instructor, Assistant Professor, Associate Professor, Professor and Acting Chief, Division of Animal Husbandry 1905–09, Chief of Division of Agronomy and Farm Management 1909–27, Chief of the Division of Agronomy, Farm Management and Plant Genetics 1927–28, Vice Director of the Minnesota Agricultural Experiment Station 1917–1937, and Professor of Agricultural Economics and Farm Management 1927–37. He retired from active duty in 1937 but was recalled for a period of nine months in 1944 to take over the duties of Acting Associate Professor of the Minnesota Agricultural Experiment Station.

Professor Boss was a fellow of A.A.A.S. and the American Society of Agronomy, member of the American Farm Management Association (president 1914), International Conference of Agricultural Economics, Sigma Xi (president Minnesota Chapter 1934–35), Alpha Zeta, Gamma Sigma Delta and the Minnesota Academy of Science.

Professor Boss is survived by his wife, two sons, and three daughters.

He held important positions apart from the University. He was in charge of the Production Control Program for the State of Minnesota 1933–36 and was a Director of the Farm Credit Administration, Seventh District, from 1934 until his death. He was a member of the Agricultural Committee, St. Paul Association of Commerce, President of the St. Anthony Park State Bank from 1934 until his death, and Economic Adviser, Bureau of Agricultural Economics, U.S.D.A., from 1926.

He was author of a book on "Farm Management" and joint author of books on agriculture designed for use in secondary schools. He was also author or joint

author of many station and extension bulletins and a voluminous contributor to the public press, especially farm papers. The statement has been made that Dr. Boss knew more farm people in Minnesota than any other member of the University staff. He was active also in civic, community and religious affairs and held important offices in the local church, its state organization and was active in Y.M.C.A. work at University Farm. A recent published statement by Dr. W. C. Coffey regarding the accomplishments of Professor Boss included the following which I quote: "A true statesman in education and research, a wise councilor, a warm-hearted friend, a builder of both institutions and men, he made a great and lasting contribution to the institution and the state he loved so well."—H. K. HAYES.

CLARENCE DORMAN

CLARENCE DORMAN, seventh director of the Mississippi Agricultural Experiment Station, died at his home on the campus of State College, February 9, following a heart attack.

He was 44 years of age and had been director of the Station since 1938.

Dr. Dorman was born in Edinburg, Mississippi, in 1902, and received his early education at the Leake County Agricultural High School in Carthage. He entered Mississippi State College in 1922, receiving the bachelor of science degree in 1926. After a year as extension specialist in Alabama, he became a graduate assistant at the University of West Virginia, where he received his master of science degree.

He became a research assistant and instructor at Michigan State College in 1931 and received his doctor of philosophy degree there the following year. In 1934 he returned to Mississippi State College as professor of agronomy and chief agronomist in the Experiment Station department of agronomy. In 1937 he was made associate director of the Experiment Station, and in 1938 he became the Station's director, succeeding J. R. Ricks, who also died of a heart attack.

He was acting president of Mississippi State College for three months in 1945 following the resignation of Dr. George Duke Humphrey, now president of the University of Wyoming, and until the coming of President Fred T. Mitchell.

He was a former president of the Association of Southern Agricultural Workers, a member of the American Chemical Society, American Society of Agronomy, Soil Science Society of America, and Sigma Xi.

Devoted to the philosophy that progress in Mississippi and the welfare of farm people could best be advanced by the application of better methods developed through research, Dr. Dorman was a ceaseless worker. In fact, his "burning the candle at both ends" had been a matter of concern to his friends for many months.

His death is thought immediately attributable to a final fight he made for the Station he loved and fought for so long. While inspecting a land-use project on an experimental unit southeast of the college, Dr. Dorman came upon a small woods fire, which he fought for about an hour and finally extinguished. He fainted three times while or after fighting the fire, but was able to return to his home after an absence of about four hours. He first appeared to be suffering from exhaustion only, but the fatal attack occurred approximately an hour later.

Under Dr. Dorman's administration, the Mississippi Station underwent the greatest expansion in its history. Successive legislatures, understanding the need for extending agricultural research, voted increased appropriations for expanding and maintenance. Two programs of extended research marked his last years of effort, one state and one national in scope.

With one exception, the branch experiment stations in Mississippi were small, inadequately supported, and incapable of carrying out their share of what Dr. Dorman conceived to be an over-all state agricultural research program. The Legislature of 1946 appropriated $312,000 for the inauguration of four new, large-scale branch stations and for increased facilities at others, and an additional appropriation of $300,000 was made for the expansion of the central station at State College.

During the past two years, he had attained national leadership and was a central figure in planning for and securing passage of greatly expanded national support of agricultural research as set forth in the Hope-Flannagan Act of Congress. As a member of the planning committee of nine, he was one of the three Southern directors to pass upon the research program for the Southern states, thus provided.

During the brief span of years allotted to him, Dr. Dorman achieved mightily. Adding to high technical education was a keen, analytical mind, a winsome personality, compassioned for the less fortunate, and abiding faith that the ills of agriculture can be and must be cured by applied research. With it all, he was wholly lovable, and will long be missed in agricultural councils.—C. Dale Hoover.

PAUL BURTCH DUNKLE

Paul Burtch Dunkle, Superintendent, Substation No. 6 of the Texas Agricultural Experiment Station, Denton, Texas, died from a heart attack at his home May 26, 1947.

He was born at Colorado Springs, Colorado, September 9, 1894. He received the B.S. degree at the A. & M. College of Texas in 1917 and the M.S. Degree in 1934. He entered military service immediately on graduation in 1917 and served as a second lieutenant, Coast Artillery Corps, U. S. Army in France for a period of 18 months from 1917–1919. On returning to civil life in 1919 he served as county agent in Texas from 1919 to 1922, when he became superintendent of Texas Substation No. 6, at Denton.

Mr. Dunkle was interested in the whole field of agronomy but devoted most of his attention to small grains, especially wheat, oats, and barley, and to legumes and grasses. He was the author of several bulletins and scientific articles on various small grain and other crops. Mr. Dunkle played a prominent part in the hard red winter wheat improvement program, which was organized in 1930. He early became the recognized agricultural leader in the region served by the Denton Station, and left his impress on agriculture in Texas.

A member of the American Society of Agronomy and the American Genetic Association, Mr. Dunkle was also active and influential in civic and religious affairs, and was a member of the Rotary Club, of other civic organizations, and of the Methodist church.

He is survived by his wife and one daughter, Sue Dunkle.—E. B. Reynolds.

BASCOM MILTON KING

Bascom Milton King was born in Stockdale, Texas, February 27, 1892. He attended Stockdale public schools, the University of Texas, and the University of Missouri. He received a B.S. degree in Agriculture from the University in 1921. After receiving an A.M. degree from the University in 1922, he became a junior agronomist with the U. S. Department of Agriculture. In 1924 he joined the faculty of the University of Missouri and became Associate Professor of Field Crops.

King was a highly efficient field agronomist. He bred and developed several new varieties of soybeans, notably Boone and S–100, and he contributed much to the improvement of varieties of small grains in Missouri. He discovered and exploited the special adaptability of Wabash heavy clay for the production of rice and soybeans, and his introduction and improvement of varieties of cotton have substantially raised the level of cotton production per acre in Missouri. He was one of the oldest and most valued members of the Department of Field Crops at the University of Missouri, and his loss is deeply felt.—W. C. Etheridge

WILLIAM WYLIE MACKIE

William Wylie Mackie, Agronomist Emeritus, University of California, died in his home in Berkely February 7, 1947. Born in San Francisco July 24, 1873, and after spending his youth and early manhood on a farm in Tulare Co. he entered the University of California in 1898 and received the B.S. degree in 1903. He held positions with the U. S. Forest Service, and the U. S. Bureau of Soils and later worked professionally in Mexico and Turkestan. During this time his experiments resulted in the successful introduction of rice culture into the central valleys of California and into the Yaqui Valley, Sonora, Mexico.

Returing to the University of California as a graduate student, Mr. Mackie received his M.S. degree in 1917. From then until he retired in 1943, Professor Mackie served the agriculture of the state first employed jointly by the University and the U. S. Department of Agriculture, later by the University alone. Cereal disease control during World War I, cereal disease investigations including cereal breeding and later plant breeding with other field crops occupied his attention.

Professor Mackie was a most tireless and productive worker, much respected both by his colleagues and the farmers. His breeding work resulted in new and improved varieties of small grains, maize, beans, and other field crops, which besides their productively were heat-resistant and drought-resistant. Many of these now widely grown, contribute immeasureably to the agricultural wealth of California. Though his main contributions were from his plant breeding work, he was author of many valuable articles in the general field of agriculture. His last is the monograph on *The Origin, Dispersal, and Variability of the Lima Bean*, a contribution of significance for phytogeography and anthropology as well as agriculture.

In 1899 he married Julia Adeline Manchester. She and their daughter, Jane Mackie Armstrong, survive him.

Professor Mackie's deepest sympathies were with the farmers whose problems he was continually trying to solve and among whom he had a host of warm friends. After his retirement even to the day of his death, Professor Mackie continued his agricultural endeavors by additional plant breeding and by work which has led to the successful establishment of rice culture in the Imperial Valley of California.

WILLIAM HORACE ROSS

In the death in Washington on May 16 at the age of 71 of Dr. William H. Ross, retired Principal Chemist, Division of Soils, Fertilizers and Irrigation, Bureau of Plant Industry, U. S. Department of Agriculture, the fertilizer industry has suffered a great loss. No other contemporary chemist has contributed so much to fertilizer chemistry as has Dr. Ross. A native of Nova Scotia, and later a citizen of the United States, he took his under graduate work and master's degree at Dalhousie University, Halifax, took work at Johns Hopkins and his doctor's degree at the University of Chicago, where he did some of the very early research work on radioactive substances under the late Dr. Herbert N. McCoy.

Dr. Ross was the country's authority on the chemistry of fertilizer phosphates and it was largely due to his researches that the true chemical composition of phosphate rock and the various compounds resulting from the acidulation of phosphate rock was determined. He also did pioneer work in the production of phosphoric acid in the electric furnace. Among other of his noteworthy research accomplishments in fertilizer chemistry were the chemistry of the ammoniation of superphosphate, the granulation of fertilizers and fertilizer materials, moisture determination, boron toxicity, and conditioning of fertilizers and fertilizer materials. His latest project was work on the use of ammonium nitrate in fertilizers, its chemical analysis and treatment to avoid caking.

After several years as chemist at the University of Arizona he joined the USDA where he remained 34 years until retirement last year. Since his retirement Dr. Ross has been a cooperator with his old Division and has also been a consultant for The National Fertilizer Association. Dr. Ross was an able and willing contributor to the technical press; more than 150 scientific papers and patents came from his pen. He was associated with CHEMICAL ABSTRACTS, being at one time assistant editor and continuously an abstractor since that journal's founding in 1907. For many years he was the Referee on Phosphates of the Association of official Agricultural Chemists and was president of that organization last year.

Dr. Ross was a captain in the Chemical War Service in World War I and he will be interred in Arlington National Cemetery. He belonged to many scientific societies among which are the American Association for the Advancement of Science, American Chemical Society, American Society of Agronomy, American Institute of Chemists.

Mrs. Ross, two sons, and a brother survive him.—Fred Lodge.

LOUIE HENRIE SMITH

Louie Henrie Smith, Chief, in charge of Publications, Soil Survey, Emeritus, of the Department of Agronomy, University of Illinois, died at Urbana, Illinois, on January 30, 1947 after an extended illness.

He was Assistant Chemist, Chief Assistant Chemist, Assistant Professor, and Professor of Plant Breeding between 1899 and 1920. From 1920 until his retirement in 1940 he served as Chief, in charge of publications of the Department of

Agronomy, Illinois Agricultural Experiment Station. In 1913–14 and again in 1918–19 he was acting head of the Department.

Doctor Smith received his Bachelor of Science and Master of Science degrees in 1897 and 1899, respectively, at the University of Illinois. The degree Doctor of Philosophy was conferred upon him in 1907 at the University of Halle, Germany, where he studied under the famous botanist, Klebs.

For more than twenty years Doctor Smith was identified with the classical experiments on the effect of selection for protein and oil and height of ear in corn, and published many bulletins and papers on them. He was a pioneer in the application of statistical methods to agricultural experiments. Doctor Smith also was one of the first to publish data from a uniformity trial on corn, indicating a recognition of the importance of the field plot problem which is receiving so much emphasis today.

Doctor Smith excelled in scientific writing. He strove always for clearness as the first requisite. As editor of Soil Survey publications and chairman of the editorial committee in the Agronomy Department, he set a high standard in preparing experiment station publications and helped especially the younger members of the department to learn the essentials of good writing.

The personal qualities of Doctor Smith were as outstanding as his contributions to the scientific work of the Agricultural Experiment Station. He was self-forgetful, and many times others received the recognition that was due him. He received his graduate training in Germany, and no doubt there received the training in thoroughness which characterized all his work. Many men owe much to Doctor Smith for his example of devotion to duty, thoroughness, and willingness to submerge himself in serving others.

Doctor Smith was the author or co-author of many bulletins, circulars, and scientific papers in which he presented the results of his research, research which was well planned, well carried out, and well reported.

He was a member of many scientific societies, including the American Chemical Society, American Association for the Advancement of Science, American Genetic Association, American Society of Agronomy, Illinois Academy of Science, Sigma Xi, Gamma Alpha, Phi Lambda Upsilon, Alpha Zeta, and Gamma Sigma Delta. He was a charter member of the American Society of Agronomy.—O. H. SEARS.

CHARLES BURGESS WILLIAMS

CHARLES BURGESS WILLIAMS, Professor Emeritus of Agronomy, at the North Carolina State College died suddenly of a heart attack at his home in Raleigh, N. C. on June 25, 1947.

Professor Williams was born at Shiloh, Camden County, N. C. on December 23, 1871. He grew up on a general farm and attended the rural schools of the district. He later attended the Shiloh High School and Military High School at Littleton. On October 3, 1889 he entered the first class of the new North Carolina A. and M. College and graduated with highest honors, having specialized in agriculture and chemistry. After serving for three years as Assistant Chemist of the North Carolina Agricultural Experiment Station, he received his M.S. degree and obtained a year's leave of absence for studying chemistry at Johns Hopkins University on a state fellowship. He returned to North Carolina in 1897 as Fertilizer Control Chemist. He served as Assistant State Chemist from 1899 to 1907, when he was appointed Director of the N. C. Agricultural Experiment Station. In 1912 he was made Vice Director of the Experiment Station and Chief in Agronomy and, during the period 1917 to 1923, served as Dean of Agriculture for the North Carolina State College. From 1923 to 1940, Professor Williams served as Head of the Agronomy Department. In 1940 he retired from administrative duties and spent the remainder of his life in writing and summarizing the results of his extensive experiments in soil management and fertilization.

Mr. Williams was one of the first people to become interested in the growing of soybeans in this country. When the soybean was first planted on a very small acreage in the eastern part of North Carolina, prior to the extensive exploration and propagation of the plant by the U. S. Department of Agriculture, he immediately recognized its worth and began a spectacular campaign to popularize the crop. His work with this plant became known all over the United States and in 1918 he was selected by "The Country Gentleman" as one of seven Blue Ribbon men and women for his research with soybeans.

Mr. Williams organized, and for approximately twenty years prior to his retirement was chairman of the Tobacco Research Committee composed of research workers with tobacco in the southeastern states. This committee has contributed noteworthy service to the tobacco industry through a coordination of the research on tobacco carried on by the several states in the region and in harmonizing the recommendations on fertilization and management of the crop.

Mr. Williams took a very active interest and leadership in soil survey work. Through his efforts, provision was made for early survey and mapping of the soils throughout most of the state.

He was listed in "Who's Who in America" for many years. He was a member of Phi Kappa Phi, the American Society of Agronomy, the National Grange, and was a fellow in the American Association for the Advancement of Science. He was a charter member of the American Society of Agronomy and its president in 1926. In 1941, the Association of Southern Agricultural Workers honored Mr. Williams for his outstanding contribution to Southern agriculture with the following citation: "Native of North Carolina, close to its soil from boyhood, graduate, with highest honors in the first class of its agricultural and mechanical colleges, he has devoted his life to its service as chemist, agronomist, Dean of Agriculture, and director of its experiment station. He has been a leader of leaders in one of the most progressive of southern states; has initiated and conducted experiments in a wide field of agricultural research, and is now honored for a long career of distinguished service to his state, his section, and his country."

Mr. Williams built a foundation which will be an eternal testimonial to his character, vision, and leadership.—RALPH W. CUMMINGS.

Minutes of the Business Meeting of the Crop Science Division

THE Crop Science Division held one general program and business meeting, 14 sectional programs, and 4 joint programs with sections of other divisions. In addition to two papers on the general program, 91 papers were presented on sectional programs and 33 on joint programs. Officers of the Crop Science Division for 1948 are Dr. H. K. Wilson, who succeeds automatically from vice-chairman to chairman of the Division, Dr. D. C. Smith, elected vice-chairman of the Division by mail ballot, and the Section Chairman, Dr. D. W. Robertson, Section I, Dr. R. L. Lovvorn, Section II, Dr. V. G. Sprague, Section III, Dr. H. M. Tysdal, Section IV, Dr. H. B. Sprague, Section V, and Dr. K. P. Buchholtz, Section VI.

A committee consisting of Kling Anderson, R. P. Murphy, and C. P. Wilsie, Chairman, was elected to organize the Forage Crop Improvement Conference for the meetings in 1948.

The reports of standing committees were read and approved. Dr. C. J. Willard moved that the crop terminology recommended at the February, 1944, meeting of the Crop Science Division (this JOURNAL, 38:361, 1944) be adopted. The motion was seconded and adopted by unanimous ballot.

After considerable discussion of the length of meetings, Dr. H. K. Hayes requested a standing vote on the question of three versus four-day meetings of the Crop Science Division. The vote showed a small majority in favor of four-day meetings.

The problem of printing or mimeographing of abstracts of crops papers was discussed. The chairman pointed out the difficulty of obtaining abstracts in time for mimeographing. It was moved by

Dr. I. J. Johnson that abstracts be accepted for mimeographing only if submitted with the title of the paper. Motion seconded and carried.

The chairman reported the establishment of Special Section VI on Weed Control during the development of the program for these meetings because of the repeatedly expressed interest in this subject. Special Sections V, Turf, and VI, Weed Control, will be continued in 1948.

OFFICERS OF CROP SCIENCE DIVISION FOR 1948

Chairman, H. K. Wilson, Pennsylvania State College, State College, Pa.

Vice Chairman, D. C. Smith, University of Wisconsin, Madison, Wis.

Past Chairman, W. M. Myers, U. S. Regional Pasture Research Laboratory, State College, Pa.

Section I—Breeding, Genetics, and Cytology

Chairman, D. W. Robertson, Colorado State College, Fort Collins, Colo.

Section II—Physiology and Ecology

Chairman, R. L. Lovvorn, North Carolina State College, Raleigh, N. C.

Section III—Production and Management

Chairman, V. G. Sprague, U. S. Regional Pasture Research Laboratory, State College, Pa.

Section IV—Seed Production and Technology

Chairman, H. M. Tysdal, Bureau of Plant Industry, Soils and Agricultural Engineering, Beltsville, Md.

Special Section V—Turf

Chairman, H. B. Sprague, Texas Research Foundation, Renner, Tex.

Special VI—Weed Control

Chairman, K. P. Buchholtz, University of Wisconsin, Madison, Wis.

COMMITTEE REPORTS

VARIETAL STANDARDIZATION AND REGISTRATION

DURING the year the activities of this Committee have been strictly limited. One application for the registration of a variety has been received and is being considered by the Committee. During the absence of the Chairman of the Crops Division on a detail in Japan, there was an unavoidable delay in the reconstruction of the Committee. As a result the Committee has been relatively inactive, although there are a number of problems which it is hoped can be submitted to the membership of the Committee for their consideration. It is hoped that during the coming year these matters can be taken up and recommendations submitted to the Society at a later date.

For the Committee:

M. A. McCall, *Chairman*

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

THE committee has made a survey of the research now being done on the genetics of wheat and this has been mimeographed and sent to about 40 wheat research workers in the United States and Canada, in an effort to stimulate further genetic research. In addition, suggestions have been made regarding the collection and storage of material suitable for the genetic and cytological mapping of the wheat genomes now made feasible by nullisomic and monosomic analysis.

J. B. HARRINGTON E. R. SEARS
L. P. REITZ S. P. SWENSON
E. R. AUSEMUS, *Chairman*

TURF

ACTING upon instructions from the Society, the Turf Committee presents this progress report on the estimate of the size, scope and value of the specialized uses of grass in the United States.

Turf Sports Fields (Athletic fields, polo grounds, drill and parade grounds, grass courts, hockey fields, playgrounds):

Total estimated "replacement value"..............$305,000,000

Over 18,000 individual fields. Source: 1940 study, National Recreation Association, New York. R. H. Morrish, G. O. Mott, and H. B. Sprage, *Chairman*.

Grass Areas in Parks:

Estimate..................................250,000 acres
Estimated acre cost of establishment or replacement...$75,000,000

Source: Parks and Recreation. G. W. Burton, O. J. Noer, and A. E. Rabbitt, *Chairman*.

Golf Courses:

	Acreage	Investment
2930 9-hole courses	123,060	39,500 each
1887 18-hole courses	149,073	363,000 each
Total estimated value	$1,000,000,000.00	

Source: Golfdom, Chicago. M. E. Farnham, H. B. Sprague, and O. J. Noer, *Chairman*.

Turf on Lawns (1 lawn to 8 persons):

Estimated number of lawns in the U. S................15,000,000
Estimated average size.............................3,000 sq. ft.
Estimated replacement value at $50.................750,000,000

M. E. Farnham, G. W. Burton, and H. B. Musser, *Chairman*.

Airfields:

Total airfields......................................4,490
Total acres...1,709,632
Total cost of establishment at $100 per acre..........$170,963,000
Total annual maintenance cost at $20.................34,192,640

R. H. Morrish, A. E. Rabbitt, G. H. Jones, and E. B. Cale, *Chairman*.

Reports are not available for roadsides and cemeteries. Excluding these areas, the total estimated value of turf in the U. S. is over 2½ billion dollars. The value to the health and better living of our people is incalculable. Virtually every man, woman and child is affected. Every acre in Turf supports the Government program of putting land in grass with the maximum control of erosion and the building of soil.

The committee recommends that a standing Turf Committee be appointed for a continuation of this study on an annual basis.

The committee expresses a unanimous opinion that the research and educational facilities in the colleges and universities are wholly inadequate in comparison with the value of the Turf industry. Only one state in 48 has provided a complete set-up of research and extension to handle the Specialized Uses of Grass. Expansion of educational facilities (extension) is in greatest need and, for this purpose, more agronomists trained in the Specialized Uses of Grass are needed.

It is further recommended that a study be made of the amount of funds expended for research and education (by states) in the Specialized Uses of Grass in relation to the value of the Industry.

It is further recommended that attention be directed to the thorough evaluation of seeds and seed mixtures offered on the market, together with an evaluation of the "nostrums" offered to the unsuspecting public.

It is further recommended that a special committee, or a subcommittee, be appointed to meet with representatives of equipment manufacturers for a study of the development of machinery required for the efficient and economical establishment and maintenance of Turf areas.

Grass breeders who have not the facilities to propagate and evaluate turf types are urged to forward seed or clonal material to those workers who are in a position to study their specialized uses.

The committee recognizes the pressing need for more fundamental studies on the response of various grasses to nutrient elements and the more efficient use of fertilizers applied to Grass. Because this study is basic to all the uses of grass, including the specialized uses, it is recommended that the Turf Committee make a study of the needs in this field with the appropriate Fertilizer sub-committees.

E. B. Cale — G. O. Mott
M. E. Farnham — O. J. Noer
G. H. Jones — A. E. Rabbitt
R. H. Morrish — H. A. Schoth
H. B. Musser — H. B. Sprague
F. V. Grau, *Chairman*

CROP TERMINOLOGY

NO REPORT of this committee was made in November, 1946. Apparently the members of the Division are very well satisfied with their terminology as it is. At all events we have had very few questions referred to us this year.

A correspondent questions the use of the term "native" with reference to pastures. This is particularly an Eastern problem. West of the Mississippi, or at least west of the Missouri, the term would mean exactly that—native undisturbed prairie or plains grasses.

However, there are many references in Eastern pasture literature to "native" pastures. It would seem that a little thought and care would avoid the use of this inaccurate term. For example, when someone reports that "Native sods liberally top-dressed with lime and a complete fertilizer made about two tons of dry matter per acre", he gives no information about the sod that was treated. It may have consisted of timothy, bluegrass, red top, broomsedge, *Danthonia*, quack grass, or a mixture of some or all of these and several other plants. If the material is worth reporting at all, it is worth telling what the predominant plant or plants in the unimproved pasture were. If a single term to replace "native" in the above connotation is required, the Committee would suggest "unimproved".

The objection to "native" is primarily its indefiniteness. Some of the plants in these "native" pastures really are native—most of them are not, but there is a complete lack of information.

2. The English tern "ley" is being more and more widely introduced in this country and was referred to the Committee for definition. No definition of the word was found in the available English dictionaries. The word is used in dozens of recent British forage crop publications but the Committee failed to find any clearly stated definition of it. Consequently, the Chairman wrote to Dr. R. O. Whyte, who in turn referred the letter to Dr. William Davies. Dr. Davies replied in part as follows:

"Ley" is the period under sown pasturage within the arable cropping rotation. The ley may be of indefinite duration, thus we speak of a one-year ley, where normally ryegrass and red clover are used as the main constituents, the grass crop occupying the land for one complete year. We may also refer to two-year leys and three-year leys, where the seed mixture that is sown is designed specifically for the period of years concerned. In actual fact, the seeds mixture designed for a three or four-year ley is likely to be one that, under good management, would last for much longer, but the essential point about the ley is that from the outset it is an integral part of the rotation and is designed ultimately to be ploughed up.

A question that is frequently asked is "When does a ley cease to be a ley?" and I think the best definition would be as follows: "A sown sward is rightly termed a "ley" as long as the species of grasses and clovers contained in it are directly attributable to the seeds that were sown, and further, that the initial design to plough as part of the rotation, is still being adhered to."

It would appear, therefore, in American terms, that the ley is the biennial or perennial hay or pasture part of a rotation including cultivated crops. It would include all seedings of biennial or perennial forage crops in this country except those which are intended to produce really permanent pasture.

3. Like the erroneous name "Reed's canary grass" which was mentioned in the first report of this committee, the name "Balboa rye" instead of "Balbo", frequently appears in farm papers and elsewhere. This valuable pasture rye was introduced by the Tennessee Experiment Station in 1933. In their Circular No. 45, which described it, the following explanation was made:

"The Experiment Station has made numerous varietal trials of rye in the hope of finding a variety of outstanding merit for Tennessee conditions. This hope has been partly realized in a variety which was received by chance from Italy about fourteen years ago. The Station has recently named it "Balbo" in honor of the Italian aviator."

In view of later events perhaps most of us would rather call it Balboa rye than Balbo rye, but the latter is correct.

G. H. AHLGREN
C. P. WILSIE
C. J. WILLARD, *Chairman*

Agronomic Affairs

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Southeastern Branch:

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Corn Belt Branch:

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D. W. Robertson, Colorado Agricultural College, Fort Collins, Colo.
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T. M. Stephenson, Central Experimental Farm, Ottawa, Canada.

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CHANGES IN SURCHARGE AND REPRINT RATES FOR 1948

CONFRONTED with steadily rising costs of publication, the Executive Committee has authorized changes in the surcharge and reprint rates for the JOURNAL for 1948. The changes bring the rates more nearly into line with actual costs than did the old schedule set up several years ago and unchanged to date. The new rates become effective with the January issue of the JOURNAL.

Surcharges for extra pages beyond the first 12 pages, will now be $5.00 a page up to and including 16 pages and $7.00 a page for each page beyond 16. The allowance of $15 for illustrations for each issue remains unchanged, but due to greatly increased photo-engraving costs represents a sharp decline. This allowance will permit the use of two, possibly three, line drawings or charts which can be reproduced as zinc etchings, or one large photograph or two small ones to be reproduced as halftones, without surcharge. An effort will be made to indicate the surcharges, if any, at the time of submitting proof on the article.

Reprint rates have been increased approximately 25%.

NEWS ITEMS

FORD M. MILAM, former research assistant in soils and crops at North Carolina State College, was recently appointed Coordinator of Agricultural Education and Research under the American Military Government in South Korea, transferring from his previous position as Advisor, Agricultural Experiment Station, in the same country. As Coordinator, Mr. Milam (who was separated from the Army Air Forces in June 1946 as a major) will supervise and determine policy for all activities of the newly established agricultural extension system, the thirteen central and branch agricultural experiment stations, and all agricultural schools and colleges in South Korea. The new extension service was originally proposed and outlined by Mr. Milam, who also acted as chairman for the drafting committee which

prepared the plan for final approval and legal establishment by the South Korea Interim Legislature.

—A—

PROFESSOR HSIANG HUANG KUANG, Head of the Department of Agronomy, College of Science, West China Union University, is now engaged in a graduate work on disease resistance of cereals under the direction of Professor F. N. Briggs of the University of California at Davis, Calif.

—A—

DOCTOR ROBERT W. ALLARD joined the staff of the Division of Agronomy, University of California, as Assistant Professor of Agronomy on June 1, 1946, to take charge of the lima bean breeding program.

—A—

WILLIAM H. BROOKS III, upon graduation from the University of California, was appointed Associate in the Experiment Station at that institution. He will be associated with the range improvement program under the direction of Dr. R. Merton Love.

—A—

ROBERT L. FORBES rejoined the staff of the Division of Agronomy, University of California, following a leave of absence of four years to serve in the U. S. Army Air Corps. Mr. Forbes is associated with the foundation seed program carried on in connection with seed certification.

—A—

LUTHER G. JONES, formerly with the U.S.D.A. Bureau of Entomology and Plant Quarantine, Cereal and Forage Division, as entomologist, has been appointed to the staff of the Division of Agronomy, University of California. His project is hay and seed production of alfalfa in California.

—A—

DOCTOR PAULDEN F. KNOWLES, formerly Associate Professor of Plant Breeding, University of Alberta, Edmonton, Canada, joined the agronomy staff of the University of California October 1, 1947, as Assistant Professor of Agronomy in charge of oil and fibre crops. His immediate problem will be concerned with flax production in California.

—A—

DOCTOR HORTON M. LAUDE has been appointed Assistant Professor of Agronomy at the University of California as plant physiologist, working on range plants.

—A—

ALFRED H. MURPHY, graduate of Oregon State College in Forestry, joined the Division of Agronomy staff of the University of California, to work under the direction of Dr. R. Merton Love on range improvement experiments in the Klamath Weed Area in the northwestern part of the state.

DOCTOR CHARLES W. SCHALLER joins the Division of Agronomy at the University of California as Instructor in Agronomy and Junior Agronomist in the Experiment Station to assist Professor F. N. Briggs on his cereal breeding program, and to assist in teaching courses in plant breeding.

—A—

DOCTOR E. H. STANFORD has rejoined the staff of the Division of Agronomy, University of California, following a leave of absence of 3 years to serve in the medical corps of the U. S. Army. Dr. Stanford is in charge of alfalfa investigations, particularly plant breeding.

—A—

D. C. SUMNER returned to the Division of Agronomy at the University of California after 3½ years service with the U. S. Army. Mr. Sumner, now an Associate in the Experiment Station, will assist Dr. R. Merton Love in carrying on experimental field work with grasses.

—A—

DOCTOR F. P. ZSCHEILE joined the staff of the Agronomy Division at the University of California as Associate Professor of Agronomy and Associate in the Experiment Station to undertake fundamental studies on the chemical nature of disease resistance in plants, also studies on some of the obscure nutritional differences in alfalfa induced by environment.

—A—

MILTON D. MILLER has rejoined the University of California staff to handle extension aspects of forage crops, including cultivated forage crops, irrigated pastures, and range improvement. He is chairman of the group of four extension agronomists on duty with the Agronomy Division.

—A—

LOREN L. DAVIS, Extension Specialist in Agronomy joined the University of California staff on September 1, 1947. He formerly was Director of the U.S.D.A. Rice Field Station, Bureau of Plant Industry, Biggs, Calif. He will now do cereal, flax, and rice crop extension work for the University of California.

—A—

MARVIN HOOVER, Extension Specialist in Cotton Production, affiliated with the University of California staff on November 17, 1947, will handle the extension aspects of cotton research and production, as well as those dealing with grain sorghums and corn.

—A—

WAYNE F. WEEKS, Extension Specialist in Sugar Beet Production, accepted his position on December 1, 1947, to conduct the extension sugar beet work for the University of California. Additionally, he will handle bean crop extension work.

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